SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Surface Active Agents—Lewis and Herndon

Sewage Chlorination Control—Henderson

Industrial Waste Problems—Giles

Milk Waste Reduction—Schwarzkopf

San Diego Bay Oxygen Study—Nusbaum and Miller

1952 Annual Index

DECEMBER, 1952—VOL. 24, No. 12

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Your prompt payment of 1953 dues will avoid interruption in receipt of SEWAGE AND INDUSTRIAL WASTES as well as other Federation services. Undue delay may make it impossible for a complete volume of the JOURNAL to be furnished.

Please remit directly to your Member Association Secretary immediately upon receipt of the first dues notice from him.

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Chicago INDUSTRIAL WASTE TREATMENT

SERVING OVER 100 INDUSTRIES

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- grease removal
- grit removal
- wastes from laundries
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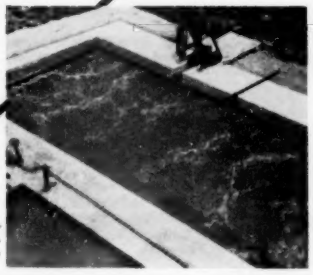
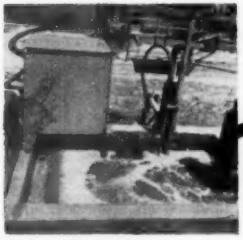
G. A. Wintzer & Son Company, Wapakoneta, Ohio. Packing house waste. Paul A. Uhlmann & Associates, Engineers.



Cherry Grove Dairy, Toledo, Ohio. Milk wastes. L. Lewandowski & Son, Engineers.



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HOW TO MEASURE TRADE WASTES ACCURATELY

In accordance with anti-pollution laws recently enacted by numerous states, most industries now face the task of purifying their plant wastes before discharging them into adjacent streams and rivers.

This purification process usually requires special plant construction, and invariably the necessity exists of obtaining flow data, whether this be the simple indication of flow rate or a more permanent method of recording and totalizing the flow through the plant. With purification processes of this kind, measuring equipment usually is located at the point of discharge of partially filled pipe or in open channels, where low heads or pressures exist and where measurement is either difficult or impossible when using standard forms of measuring instruments.

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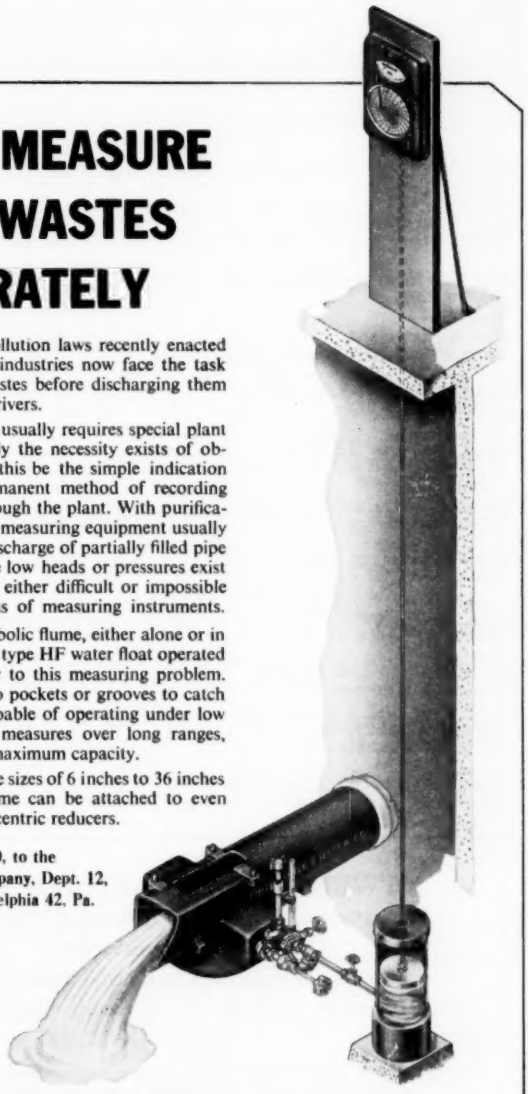

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Association	*Place*	*Time*
New York Sewage and Industrial Wastes Assn.	Hotel New Yorker, New York City	Jan. 22–23, 1953
Texas Water and Sewage Works Assn.	Texas A & M College, College Station, Tex.	Mar. 8–12, 1953
New Jersey Sewage and Industrial Wastes Assn.	Hotel Traymore, Atlantic City, N. J.	March 11–13, 1953
Arkansas Water and Sewage Conference	Hotel Marion, Little Rock, Ark.	Mar. 16–18, 1953
South Carolina Water and Sewage Works Assn.	Clemson College, Spartansburg, S. C.	Apr. 2–4, 1953
Kansas Sewage and Industrial Wastes Association	Hotel Broadview, Wichita, Kans.	Apr. 22–24, 1953
California Sewage and Industrial Wastes Association	Mar Monte Hotel, Santa Barbara, Calif.	Apr. 22–25, 1953
Arizona Sewage and Water Works Assn.	San Marcos Hotel, Chandler, Ariz.	Apr. 23–25, 1953
Central States Sewage and Industrial Wastes Assn.	Hotel Pere Marquette, Peoria, Ill.	June 3–5, 1953
Ohio Sewage and Industrial Wastes Treatment Conference	Mayflower Hotel, Akron, Ohio	June 17–19, 1953
Pennsylvania Sewage and Industrial Wastes Assn.	Pa. State College, State College, Pa.	Aug. 26–28, 1953
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Owensboro Hotel, Owensboro, Ky.	Sept. 21–23, 1953

TWENTY-SIXTH ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
Florida Sewage and Industrial Wastes Association
Municipal (Bayfront Park) Auditorium, Miami, Florida
October 13–16, 1953

Address hotel reservation requests to: FSIWA Convention Housing Bureau, 320 N.E. Fifth Street, Miami, Florida

Nebraska Sewage and Industrial Wastes Association	Hotel Capitol, Lincoln, Nebr.	Nov. 12–13, 1953
Florida Sewage and Industrial Wastes Association	San Carlos Hotel, Pensacola, Fla.	Nov. 16–19, 1953

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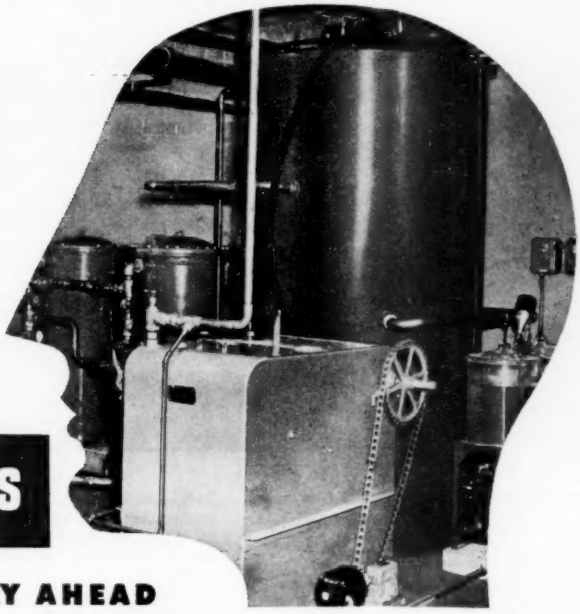

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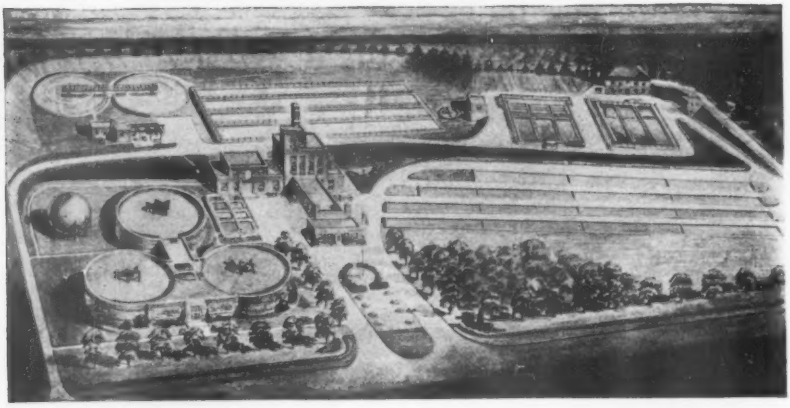

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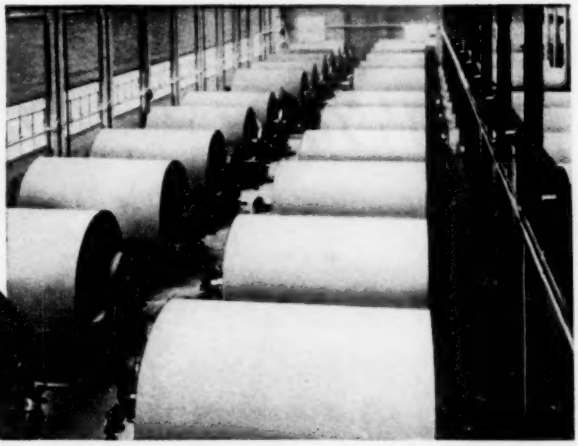

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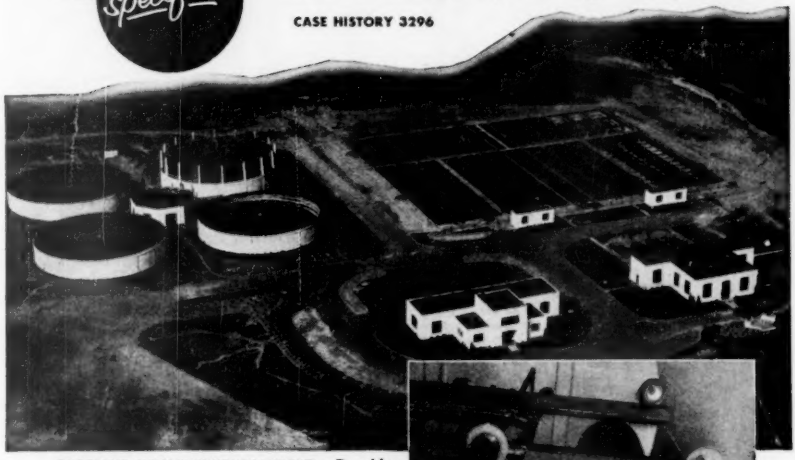

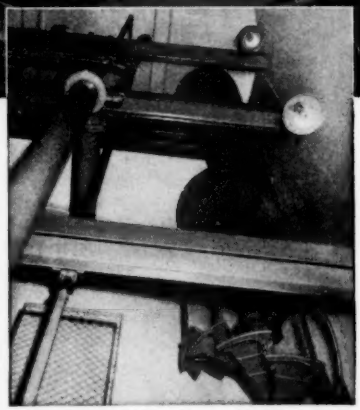

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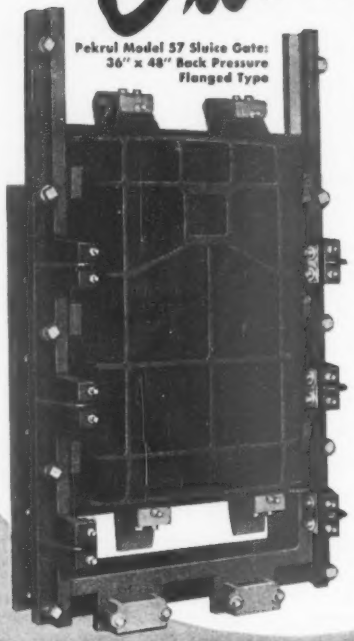

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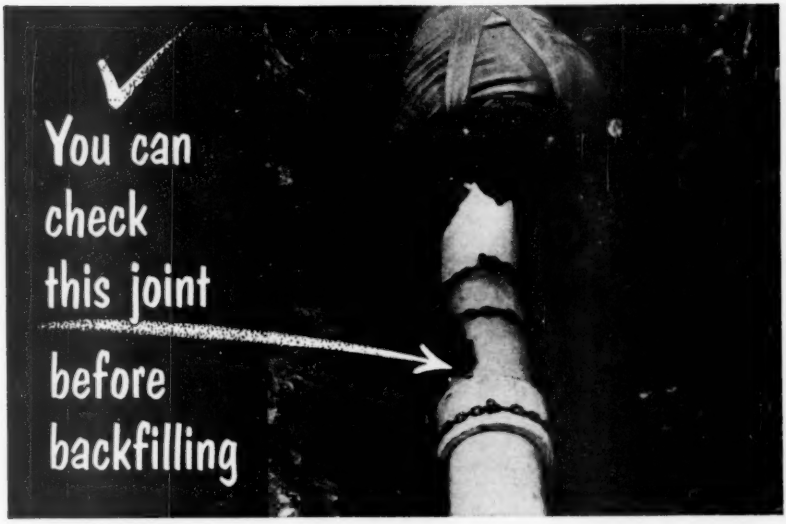

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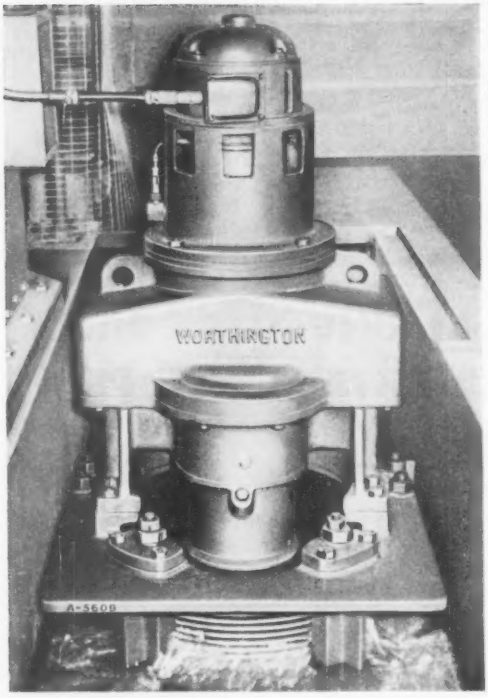

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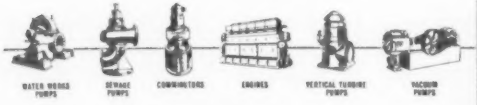

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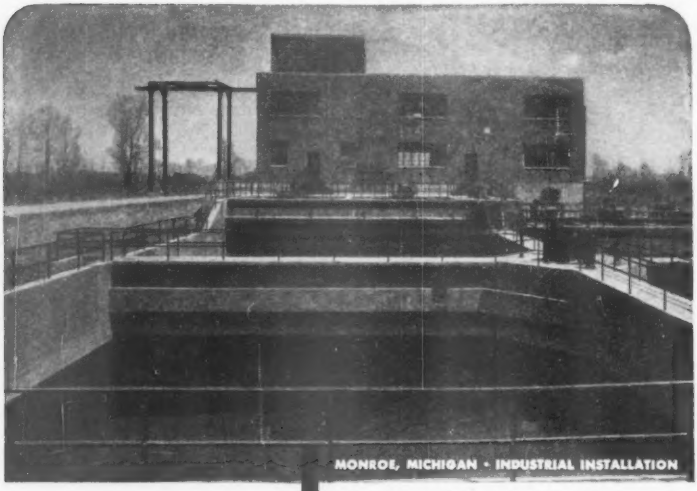

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 24 **December, 1952** **Number 12**

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New England Sewage and Industrial Wastes Association 498a

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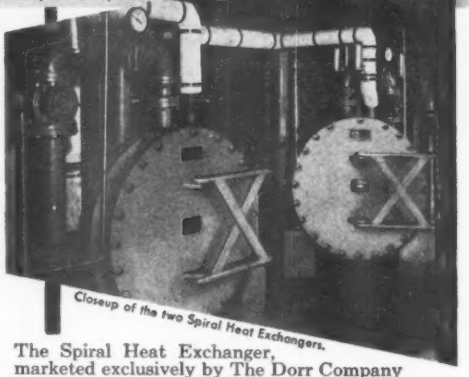

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Sewage Works

MEASUREMENT OF SURFACE TENSION OF SEWAGE
II. Indianapolis Studies

By D. R. Bowers

Chief Chemist, Sanitary District of Indianapolis, Ind.

With the upgrowth of operational and laboratory experience, it becomes increasingly evident that the answers to many problems of sewage treatment reside in the physicochemical aspects of sewage. Surface tension must be regarded ostensibly as one of these aspects. Some of the theoretical considerations, apparatus, basic techniques employed, and certain difficulties encountered in the measurement of surface tension of sewage already have been presented (1) and serve as an introduction to the data summarized here.

At the outset it was desired to determine the relative surface tension values for raw sewage, primary effluent, and final effluent. Due to peculiarity of design of the Indianapolis, Ind., plant, however, a true "raw" sample cannot be obtained. Therefore, when a value is given for raw sewage for the Indianapolis plant, it is of a "synthetic" sample obtained by the compositing of several sampling stations in the primary treatment units. In order to have reliable and easily obtained samples, the surface tension study was necessarily limited to the primary effluent (a combination of fine-screened and rapid settled material) and the final effluent (partly plain aeration and partly activated sludge process). It should be explained that the primary treatment at Indianapolis is exceedingly inadequate and only a small reduction of either B.O.D. or suspended solids is accomplished.

Limited Range of Values

Before encountering any tabulations of data it is necesary to appreciate that a numerically narrow range is confronted in measuring the surface tension of sewage. In nearly three years of surface tension determinations at Indianapolis a range of only 32.7 dynes per centimeter was found, the confines of this range being a minimum of 38.9 and a maximum of 71.6 dynes per centimeter. Further, the vast bulk of observed values fell between the values of 40 and 60, the majority of these values being limited to between 45 and 55 dynes per centimeter. With this decided lack of latitude, the problem of correlation with other values for sewage is difficult.

Other Data Scarce

At best, of course, the surface tension of sewage must be regarded in a special and somewhat arbitrary category. Normally surface tension is considered for pure substances or relatively simple solutions for which other pertinent physical data can be computed. In the case of sewage some of the other data, such as gram-formula weight, are unobtainable.

Since it was not possible to establish an accurate temperature correction factor, it was decided more desirable to adjust the temperature of samples used for comparative purposes. As a matter of convenience, 25° C. was chosen as an easily achieved and basic reference temperature. The data pre-

sented in the following are, consequently, for samples thus adjusted.

Contributing Factors

This first report of surface tension findings is an attempt to evidence normal ranges of surface tension values and their relationship to other measurable ratings of sewage. In the measurement of the two basic samples, primary and final effluent, solids appeared as ready reference values. In the first year of observation 60 to 80 per cent of the samples showed an inverse relationship of change for solids as compared to surface tension.

It is not intended necessarily to imply that the solids, as such, are the contributing factor, but rather that the solids as a measure of the relative strength and quantity of substances present are a measure of the factors which would potentially contribute to the changing of surface tension. An accessory role of many of the constituent classes of material in wastes is that of changing the surface tension of water. Some of the classes of substances found in sewage which would effect such a change in surface tension are: proteins and their hydrolysis products, esters, ethers, fatty acids, alcohols, fatty alcohol sulfates, sulfonates, inorganic compounds, and others too numerous to mention.

Whereas all these classes may or may not be introduced daily into the sewage, and even if the sum total of solids would remain constant, the varying relative proportions of the aforementioned classes would obviate any possibility of proving a quantitative correlation of surface tension with solids.

TABLE I.—Relationship of Total Solids and Surface Tension

Total Solids (p.p.m.)		Mean Surface Tension (dynes/cm.)
Range	Mean	
500- 599	578	61.3
600- 699	667	52.5
700- 799	748	55.6
800- 899	853	54.1
900- 999	953	52.7
1000–1099	1044	48.7
1100–1199	1135	48.1
1200–1299	1220	47.0

TABLE II.—Relationship of Dissolved Solids and Surface Tension

Dissolved Solids (p.p.m.)		Mean Surface Tension (dynes/cm.)
Range	Mean	
400–499	413	60.2
500–599	552	64.7
600–699	659	62.5
700–799	775	59.9
800–899	850	57.6
900–999	926	56.8

Hundreds of measurements have been made at Indianapolis and are summarized in Tables I, II, and III. The inverse relationship is readily seen wherein the surface tension diminishes as the solids increase. The surface tension measurements were made on the whole sample, as received, in the cases of the data presented in Tables I and III for total and suspended solids, respectively. A special procedure was used for obtaining a sample for surface tension measurements in the case of dissolved solids presented in Table II. The sample used was, in effect, the filtrate from suspended solids determinations. The filter flask used was scrupulously cleaned and upon filtering a given sample, the filtrate was transferred from the filter flask to the dish used in the measurement of surface tension.

As in the case of individual values for suspended solids, the narrow category increments of 10 p.p.m. show only a weak trend of diminishing surface tension with increasing solids; however, in the broad increments of 50 p.p.m. a more definite trend can be seen. Table IV is merely a condensation of the data of Table III, presented to facilitate observation of the trends expressed.

Obviously, an attempt to make a quantitative correlation of surface tension, which is susceptible in varying degrees to varying quantities and types of substances, with sewage, which is composed of varying quantities and types of substances, on a basis of the aggregate solids, would be impractical. However, the qualitative relationship appears not to be denied. From the evidence it may be said that the surface tension varies inversely with the quantity of solids material present in the sewage, subject to the relative surface active properties of said solids.

A special procedure was followed further to observe the solids-surface tension relationship and later for the purpose of determining specific effects of detergents. Rather than depend upon chance encountering of a set of varying solids and further to determine actually what relation the same solids in different concentration would hold with surface tension, a number of successively diluted samples were prepared for measurement. This procedure evidenced the effect of particular solids variation proportionally and not extreme quality or type variation as more likely would be encountered daily.

TABLE III.—Relationship of Suspended Solids and Surface Tension

Suspended Solids (p.p.m.)		Mean Surface Tension (dynes/cm.)
Range	Mean	
0– 9	6	62.8
10– 19	14	67.7
20– 29	26	55.9
30– 39	35	55.3
40– 49	45	54.2
50– 59	53	54.1
60– 69	63	52.8
70– 79	74	54.0
80– 89	85	54.5
90– 99	95	52.4
100–109	105	54.1
110–119	115	50.3
120–129	125	49.3
130–139	135	48.8
140–149	142	48.0
150–159	154	49.7
160–169	165	48.2
170–179	174	47.8
180–189	185	48.5
190–199	195	48.2
200–209	203	48.3
210–219	213	48.5
220–229	224	47.4
230–239	234	48.1
240–249	243	51.1
250–259	256	47.6
260–269	263	48.3
270–279	274	49.4
280–289	282	55.1
290–299	294	47.2
300–399	336	48.3
400–499	466	43.1

TABLE IV.—Relationship of Suspended Solids and Surface Tension

Suspended Solids Range (p.p.m.)	Surface Tension (dynes/cm.)	
	Mean	Range
0– 50	55.9	47.4–71.6
51–100	53.6	44.5–62.0
101–150	49.5	44.3–55.9
151–200	48.4	42.2–56.0
201–250	48.1	42.9–51.6
251–300	48.9	44.1–59.7
301–400	48.3	42.5–52.3
401+	43.4	42.1–45.7

Solids Samples

A set of 10 samples was used, diluted with distilled water. The whole sample was taken as 100, then 90 ml. of the whole sample was diluted with 10 ml. of water, another of 80 ml. of whole sample plus 20 ml. of water, etc., to a final sample of 10 ml. of the whole sample plus 90 ml. of water, to yield a set varying from 10 per cent to 100 per cent of the solids of the original sample. The prepared samples were transferred from the graduated cylinders, in which the dilution measurements were made, to the dishes used for the surface tension measurement. The temperature was adjusted to 25° C., after which the measurement was made. The results of these determinations (Table V) serve to substantiate the definite inverse relationship of surface tension with both total and suspended solids. Both parts of

TABLE V.—Relationship of Total and Suspended Solids in Diluted Sewage and Surface Tension (Means of 100 Sets of Measurements)

Total Solids (p.p.m.)	Surface Tension (dynes/cm.)	Susp. Solids (p.p.m.)	Surface Tension (dynes/cm.)
108	56.3	21	55.5
216	53.9	43	53.5
323	52.1	66	52.2
432	50.9	87	50.5
539	50.2	111	50.6
641	50.2	124	49.4
767	48.2	155	48.2
854	47.4	177	47.3
961	46.5	200	46.6
1078	44.4	222	45.1

Table V represent the mean of 100 sets of measurements. For the most part, solids determinations were made only on the whole (100 per cent) and the 50 per cent samples, the other solids values being calculated on the basis of these and the volumes used. Graphic representation of the data (Figure 1) shows the mean values from Table V and the scatter of individual sets of measurement. Distilled water served as a control for these as well as for other surface tension determinations.

Effect of Treatment

Another expected consequence of the inverse relationship of solids and surface tension is that the reduction of solids as a result of sewage treatment would be accompanied by an increase in the surface tension of the respective samples. Table VI shows that there is invariably an increase in surface tension with a reduction of solids, although the degree of change is not necessarily proportional. The data are grouped according to broad 10 per cent reduction values in Table VII, where averages of reduction of solids and increase of surface tension show a more proportionate trend of relationship.

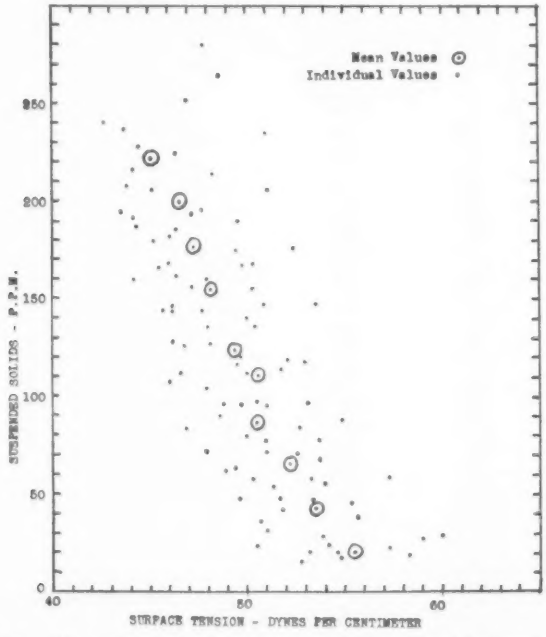

FIGURE 1.—Effect of suspended solids on surface tension of Indianapolis sewage.

TABLE VI.—Relationship between Suspended Solids Reduction by Secondary Treatment and Increase in Surface Tension

Susp. Sol. Red. (%)	Surf. Tens. Increase (%)	Susp. Sol. Red. (%)	Surf. Tens. Increase (%)
16	13	69	8
19	9	69	8
24	20	69	19
37	7	69	22
40	14	70	9
43	7	70	19
43	2	71	1
44	4	71	5
45	8	71	18
46	10	71	25
46	14	71	35
47	6	72	10
52	8	72	13
52	10	72	17
53	14	72	24
54	7	73	6
56	14	74	14
57	3	74	16
58	15	75	8
58	19	75	13
59	6	76	6
59	11	76	8
59	13	76	10
60	5	76	15
60	17	76	20
61	7	76	36
61	14	77	10
62	3	77	15
62	14	78	12
62	18	78	12
63	8	78	13
63	37	78	14
63	42	78	23
64	11	79	9
64	13	79	11
64	13	79	12
66	5	80	6
66	12	80	18
67	12	80	19
67	14	81	8
67	18	81	11
67	18	82	18
68	3	83	11
68	3	83	18
68	10	85	9
68	16	85	11
68	17	85	23
68	18	85	25
68	22	85	28
69	3	87	18

Daily Variation

As a matter of general interest, the results of measurement of primary effluent surface tension have been compiled according to days of the week in Table VIII. The data for the year 1952 are for the first six months only. There is apparently a general characteristic for a rise of surface tension on Saturday and Sunday, and a lower somewhat varying tendency for Monday through Friday. Considerable speculation could ensue from this information regarding weekends. At Indianapolis frothing does not constitute a major problem, occurring only infrequently. It is the usual experience that when frothing does occur, it is on Sunday or very early Monday morning. It may well be that in spite of a lesser quantity of material present in the sewage at these periods, there is a higher concentration of surface active compounds which would promote sudsing and frothing.

TABLE VII.—Summary of Per Cent Reduction of Suspended Solids and Per Cent Increase in Surface Tension

Susp. Sol. Red. (%)		Surf. Tens. Increase (%)	
Range	Mean	Range	Mean
80–89	83	6–28	16
70–79	75	1–36	14
60–69	65	3–42	14
50–59	56	3–19	11
40–49	44	2–14	8

TABLE VIII.—Surface Tension Averages, by Days of the Week

1950	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Mean	[1]	47.3	47.3	46.8	47.4	47.8	48.4
Max.	/	50.3	49.0	49.5	50.0	50.5	52.5
Min.		43.5	46.2	43.2	44.3	45.2	44.6
1951	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Mean	[2]	48.4	48.2	48.6	48.7	49.8	50.0
Max.		51.5	52.0	51.0	55.9	52.3	53.2
Min.		44.1	46.7	46.2	47.0	46.2	46.4
1952	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Mean	51.5	47.0	47.5	45.8	47.7	47.9	48.2
Max.	60.0	51.0	53.4	50.8	52.3	54.1	50.0
Min.	45.0	43.4	42.9	42.2	43.7	44.3	47.6

[1] Data insufficient.
[2] Data not available.

Effect of Aeration

One of the most interesting aspects of the study of surface tension at Indianapolis involves that of aerators in the secondary treatment units. Theoretically, when the surface tension of an aqueous medium is lowered, wetting of solid particles is expedited with the concomitant exclusion of entrained air from the surfaces of the solids. The question of the extent to which surface tension would affect the maintenance of dissolved oxygen in aerator passes seemed worthy of investigation. The information of Table IX(*a*) summarizes the study of dissolved oxygen and surface tension in the plain aeration process. The factor based on million cubic feet of air per day per m.g.d. of sewage is given as further pertinent information. A trend for higher dissolved oxygen is shown in accompaniment with higher surface tension values. Similarly, but to an even greater extent, the data of Table IX(*b*) show this relationship. This is a summary of the same nature for the activated sludge process. An additional column is given, the mixed liquor solids, which is also a relevant factor for consideration. When due allowance is made for the quantity of air, the sewage flow, and the mixed liquor solids, there is definitely a higher quantity of dissolved oxygen maintained at higher surface tension levels. In all cases samples were taken from the last pass of four-pass aerators. The data of Table IX(*b*) are offered in two manners with respect to the dissolved oxygen range (and mean) for clarity and verification of the trend. By plotting surface tension against dissolved oxygen (Figure 2), it may be seen further that two broad categories are encountered in both the plain aeration and activated sludge processes; namely, above and below 3 p.p.m. dissolved oxygen.

The ultimate value and appreciation of this relationship is not fully developed. From what progress has been made, however, it may be said that there is apparently a distinct relationship between surface tension, dissolved oxygen, quantity of air, quantity of sewage, and solids concentration.

TABLE IX.—Aerator Dissolved Oxygen and Surface Tension

Diss. Oxygen (p.p.m.)		Surface Tension (dynes/cm.)	Cu. Ft. Air/Gal. Sewage	Mixed Liquor Susp. Sol. (p.p.m.)
Range	Mean			
		(*a*) Plain Aeration		
0.0–0.9	0.5	51.7	0.43	—
1.0–1.9	1.3	52.8	0.43	—
2.0–2.9	2.6	52.3	0.56	—
3.0–3.9	3.5	55.4	0.45	—
4.0–4.9	4.4	55.0	0.41	—
5.0–5.9	5.3	54.8	0.71	—
		(*b*) Activated Sludge		
0.0–0.9	0.6	53.7	1.59	3,030
1.0–1.9	1.3	58.9	1.37	2,370
2.0–2.9	2.2	59.2	1.56	2,510
3.0–3.9	3.4	59.9	1.53	2,530
4.0–4.9	4.5	60.6	1.52	2,530
5.0–5.9	5.6	61.5	1.55	2,520
6.0–6.9	6.4	61.8	1.66	2,540
7.0–7.9	7.1	63.1	1.61	2,490
8.0–8.9	8.5	64.5	1.50	2,680
0.5–1.4	1.0	57.7	1.59	2,600
1.5–2.4	2.0	58.1	1.47	2,440
2.5–3.4	3.1	58.9	1.55	2,680
3.5–4.4	4.0	59.8	1.59	2,560
4.5–5.4	4.9	61.2	1.56	2,580
5.5–6.4	5.9	61.2	1.55	2,520
6.5–7.4	6.9	62.3	1.73	2,500

Syndet Studies

Departing from the initial purpose of the surface tension measurement of sewage at Indianapolis, an attempt to demonstrate relative effects of synthetic detergents has been made in view of growing general concern regarding possible deleterious effects of the increasingly popular agents to sewage treatment.

To obtain an evaluation of consumption of synthetic detergents in Indianapolis, an estimate was made based on

an inventory of 50 representative retail outlets conducted and published by Indianapolis Newspapers, Inc. (*Indianapolis Star* and *News*). In addition to the inventory statistics, the Consumer Analysis, which is a preference study (also conducted by Indianapolis Newspapers, Inc.), was consulted for a basis of confirmation of the estimate. For the year 1950 a value of 8,760,000 lb. of synthetic detergents was obtained, which is equivalent to approximately 24,000 lb. per day. The average daily sewage flow measured at the Indianapolis plant in 1950 was 69.2 m.g.d.; thus, about 42 p.p.m. of synthetic detergents (commercial form) was estimated to have existed in the sewage during that year.

It is encouraging that this value agrees favorably with the value of 45 p.p.m. given for Aurora, Ill., by Sperry (2). The Indianapolis population, sewage flow, and estimated consumption of syndets are all slightly more than 10 times those of Aurora, Ill. The average hardness of Indianapolis water is approximately 270 p.p.m., which is offered for comparison with the 370 p.p.m. given for Aurora. During the period for which the estimate was made for Indianapolis, the domestic laundry and dishwashing application of soap and synthetic detergent was apparently very nearly equal.

To exploit the previously described procedure of diluting sewage samples, it was simply amplified to include sets of samples with added synthetic detergents. A set was prepared by adding 0.1 g. per liter of a given synthetic detergent, which adulterated sample was then diluted in the manner described for the solids tests. Thus a set of 10 samples was obtained containing from 10 per cent of the solids plus 10 p.p.m. of the detergent to 100 per cent of the solids plus 100 p.p.m. synthetic detergent. A control set was prepared as described above consisting of 10 samples without the detergent.

Based on the estimate of 42 p.p.m. for the concentration of synthetic detergents already present in the sewage, this addition increases the total concentration in the whole sample (100 per cent of the solids plus 100 p.p.m. detergent) more than three times. It is not anticipated that this concentration will be encountered soon, but the amount of 100 p.p.m. was chosen as an arbitrary and convenient quantity simply to determine the effect of additional synthetic detergent in the sewage. The results of such determinations are shown in Table X in which five different brands and three different types are included; detergents A, B, and C are of the anionic type, D is cationic, and E is a non-ionic type of detergent.

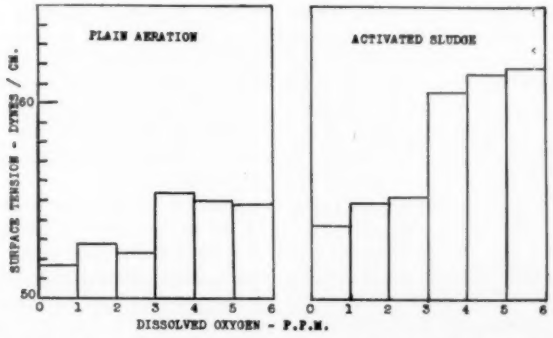

FIGURE 2.—Effect of aerator dissolved oxygen on surface tension of sewage treated by plain aeration and activated sludge.

TABLE X.—Synthetic Detergent Addition (100 P.P.M. Added to Whole Sewage Sample and Successively Diluted)

Sample	Per Cent Sample by Volume									
	10	20	30	40	50	60	70	80	90	100
Total solids +Syndet A	125	251	376	501	627	752	878	1003	1128	1253
Surf. tension +Syndet A	53.3	52.8	49.7	48.1	47.2	44.7	45.3	43.8	43.2	42.4
Total solids (control)	114	229	343	458	573	689	804	919	1033	1148
Surf. tension (control)	55.4	53.8	52.1	50.5	50.5	49.5	48.5	47.6	46.7	44.9
Total solids +Syndet B	109	219	329	438	548	658	767	877	986	1095
Surf. tension +Syndet B	53.4	49.4	46.3	45.5	43.7	43.0	41.4	40.3	39.7	37.6
Total solids (control)	100	200	300	400	500	600	700	800	900	1000
Surf. tension (control)	56.1	52.9	51.3	50.5	49.3	47.5	47.2	45.9	45.8	44.0
Total solids +Syndet C	113	227	340	453	567	680	794	907	1025	1134
Surf. tension +Syndet C	51.7	48.8	46.7	43.9	42.9	41.7	40.7	40.0	39.1	36.6
Total solids (control)	103	206	310	413	516	619	723	825	929	1032
Surf. tension (control)	57.4	52.8	50.3	48.7	47.3	46.3	46.1	44.6	44.3	42.1
Total solids +Syndet D	118	237	355	474	592	710	829	946	1068	1183
Surf. tension +Syndet D	50.5	43.9	42.2	40.3	38.6	38.1	37.4	36.1	35.9	33.8
Total solids (control)	108	217	326	434	542	651	759	867	976	1084
Surf. tension (control)	55.1	54.6	50.9	49.4	47.3	45.6	45.4	45.4	44.4	43.5
Total solids +Syndet E	118	236	353	472	589	706	824	943	1060	1177
Surf. tension +Syndet E	45.3	43.6	42.8	42.5	41.6	41.4	40.2	38.8	38.1	37.4
Total solids (control)	107	215	322	430	537	645	753	860	968	1074
Surf. tension (control)	59.5	54.4	53.7	52.9	50.9	48.9	48.2	46.8	45.0	42.7

The consistent reduction of surface tension of the sample containing additional detergent when compared to the respective control sets clearly indicates the powerful effect of these agents.

To be sure, anionic detergents received the emphasis of attention in the study of effects of additions to sewage. Some of the substances investigated, other than synthetic detergents, which lowered the surface tension of sewage were peptone, glycerol, and castile soap, none of which exhibited the striking and consistent effect found for the syndet group. Certain inorganic salts, such as ferric chloride, were found to raise the surface tension, as would be expected. Table X represents the mean of 50 sets of samples for each detergent and its control set. From these data it may be concluded that, in all probability, with respect to surface tension, most of the lowering effect of syndets is already manifest and that anticipated increases in use will not lower the surface tension of the Indianapolis sewage by more than a few dynes per centimeter.

The lack of data prior to popularization of synthetic detergent use is, of course, a distinct disadvantage. Rather than simply bemoan this lack it is preferable to make the assumption that syndets have effected a general lowering of the surface tension of sewage and that their expected increased usage will cause an additional lowering in the future. Beyond this, however, it must be remembered that the very character of sewage is such that a low surface tension would be expected in spite of synthetic detergents.

Surface tension is only one small tool in the examination of the complexities of sewage and sewage treatment. Many other phenomena remain to be recognized and explored before the physicochemical aspects of sewage can be understood. For example, it is well-known that solubilization can be accomplished

for aqueous suspensions without a lowering of surface tension. Difficulties in settling of sewage due to protected dispersed solids are not based on the surface tension factor, but rather are the result of micellar conditions. It cannot be denied, however, that deflocculation may result from the presence of surface active agents such as synthetic detergents. This can be deduced by considerations of energy, where it follows that less work is required to separate particles in a flocculate as the surface tension of the medium is lowered.

It is not the purpose of this paper concerned with surface tension measurement to offer any arguments pertaining to the so-called detergent problem in sewage treatment. However, it is difficult to avoid expressing the opinion that syndets are guilty at most of only slightly increasing an already difficult problem.

Summary

Surface tension has been under investigation at the Indianapolis Sanitary District laboratory as one of the important physicochemical aspects of sewage.

1. The normal range of surface tension of Indianapolis sewage was found to be between the narrow confines of 38.9 to 71.6 dynes per centimeter.

2. From the data resulting from nearly three years of measurement, there is evident an inverse relationship of surface tension and solids, subject to the relative surface active properties of the solids. This is verified by special deliberate dilution of sewage samples.

3. To a fairly consistent degree, a greater concentration of dissolved oxygen is observed at higher surface tension levels.

4. Further increased usage of synthetic detergents will continue to cause a slight reduction of surface tension of the sewage; however, the probability is that the majority of effect already is present.

Acknowledgment

The author wishes to acknowledge the invaluable aid of Ingle R. Harris for numerous accessory laboratory determinations relative to the investigation described.

References

1. Bowers, D. R., "Measurement of Surface Tension of Sewage. I. Fundamental Considerations." THIS JOURNAL, **24**, 9, 1069 (Sept., 1952).
2. Sperry, W. A., "Detergents and Their Influence on Sewage Treatment." THIS JOURNAL, **23**, 12, 1469 (Dec., 1951).

CORRECTION

In the article "Aeration Efficiency and Design. I. Measurement of Oxygen Transfer Coefficient," by W. Wesley Eckenfelder, Jr. (THIS JOURNAL, 24, 10, 1221; Oct., 1952), the following corrections should be made:

1. Under "Notation" (p. 1221), K_d should be "oxygen transfer rate coefficient per unit of concentration gradient."

2. In Tables I and II (pages 1226 and 1227), k_d should likewise be "oxygen transfer rate coefficient per unit of concentration gradient."

3. In Figures 1 and 2 (pages 1224 and 1225), the right-hand ordinate should read "Oxygen Uptake Rate $K_r \times W$."

THE DETERMINATION OF SURFACE ACTIVE AGENTS *

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For many centuries soap made by saponification of natural fats and oils was practically the only surface active agent available for household and industrial use. Soaps, however, have certain serious limitations, which were tolerated as long as other surface active agents were not available. The most serious was the precipitation and consequent loss of effectiveness in the presence of numerous substances such as acids and metallic ions.

The first of the surface active agents differing from fatty soaps were the sulfated oils, which were introduced in the late 1800's as wetting and emulsifying agents in the textile industry. The next important step came during World War I, when, in Germany, the war emergency led to the production of the lower alkylated naphthalene sulfonates for soap substitutes. Although they were resistant to hard water and acids, they were inferior to soap in detergency.

From the late 1920's to the present, hundreds of synthetic surface active agents have been developed and patented, including fatty alcohol sulfates, sulfonated fatty-acid amides, alkylaryl sulfonates, fat or rosin-based non-ionic esters, non-ionic ethers, condensates of fatty amides, and quaternary ammonium compounds. As of 1950, soap was still the most widely used, but production of synthetic surface active agents had increased until in 1950, according to the American Association of Soap and Glycerine Producers, the tonnage of synthetic detergents equaled more than 30 per cent of the total production of soap plus synthetic detergents. This figure amounted to only about 4 per cent as recently as 1945, which illustrates the tremendous growth that has taken place in the production of synthetic detergents in the short space of five years.

It may be seen, therefore, that the use of synthetic detergents and other synthetic surface active agents has increased to such an extent that they comprise a large part of the surface active material present in liquid wastes discharged from industrial and domestic sources.

Sewage treatment plants have experienced new operating difficulties in the past few years, which have coincided with the tremendous increase in the use of synthetic surface active agents, and which have been attributed by some observers to the presence of synthetic surface active agents in the water reaching these plants.

One of the chief difficulties which has faced investigators who wish to know whether these problems may correctly be attributed to the presence of synthetic surface active agents, has been the lack of satisfactory methods for the determination of low concentrations of such agents.

The present investigation was initiated for the purpose of studying the methods which had previously been proposed for the determination of synthetic surface active agents in dilute

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solution, the evaluation of these methods, and the development of new or improved methods where available methods were not satisfactory.

Selection of Typical Synthetic Surface Active Agents

One of the important points which was observed in the literature regarding surface active agents in general, was that chemical structure is not the primary factor in determining the properties of the agents in solution. On the contrary, as pointed out by Anson (1), the general size and shape of the hydrophobic group and the charge and location of the hydrophilic group largely determine such properties. Thus, in working out methods of determination the problem was greatly simplified by the choice of a small number of representative types from the hundreds of commercial formulations on the market.

The list of McCutcheon (2) served to aid in the selection of representative types from the trade-named materials, which often contain no reliable clue in the trade name to the identity of the active ingredient.

Existing Analytical Methods

A survey of the literature for existing methods revealed the fact that these methods may be classified into the following six related groups:

1. Single-phase titration.
2. Two-phase titration.
3. Colorimetric determination.
4. Turbidimetric titration.
5. Tensimetric method.
6. Polarographic method.

It was possible to select certain methods from the list which were attractive with regard to development for use in the analysis of industrial wastes and polluted waters. It seemed reasonable to assume that great accuracy is of lesser importance in the routine analysis of complex industrial wastes than the consideration of simplicity of method, equipment, and adaptability to industrial or sanitation laboratory conditions.

The turbidimetric method of Lambert (3) involves the use of a photometer to measure accurately the turbidity produced by the titration, but with the exception of this special equipment the method was claimed to be rapid and simple in operation.

The two-phase titration methods of Epton (4), Barr, Oliver, and Stubbings (5), and Wijga (6) also appeared to be suitable for investigation. The advantage of a two-phase titration method is that it is simple in procedure, rapid in operation, and requires no special apparatus.

Turbidimetric Titration

Investigation

The turbidimetric titration method for determining surface active agents in dilute solution depends upon the fact that the mixing of solutions of oppositely charged colloidal electrolytes results in a turbidity which reaches a maximum at or near the equivalence point. This principle was applied by Lambert (3) to the determination of a number of colloidal surface active agents in distilled water.

The turbidity produced may conveniently be measured by using any of a number of conventional colorimeters commercially available. The chief requirement for a suitable colorimeter is that it should allow access to the sample cell during the determination, in order that a stirrer may be introduced for continuous or intermittent agitation of the solution, and that the standard solution may be discharged directly into the sample cell from a buret.

In the determination of anionic agents, a standard solution of a cationic agent was added from a buret to the sample in small increments, with stirring, until the maximum turbidity was reached, as indicated by the colorimeter. The concentration of the

anionic sample in parts per million was calculated from the volume of standard cationic solution consumed in the titration. The cationic agent used in the present investigation was cetyl trimethyl ammonium bromide (CTAB). Two colorimeters were used, the Evelyn * and the Lumetron.†

Method Used

Scope—This method was used for determining anionic surface active agents in distilled water in the range of 10 to 1,000 p.p.m. of active ingredient.

Apparatus—(a) Photoelectric colorimeter. Most of the tests were made with a Lumetron Model 402B photoelectric colorimeter. This is a two-cell type containing a balanced optical system consisting of a measuring photo-cell and a balance photo-cell in a bridge circuit.

Some tests were made with an Evelyn (7) photoelectric colorimeter, which is a single barrier-cell instrument in which light is furnished by a flashlight bulb. The cells are 50-ml. test tubes, specially selected for identical optical properties.

(b) Microburet, 5-ml., calibrated in 0.01-ml. divisions.

(c) Motor-driven stirrer.

(d) Stopwatch.

Reagents—0.00267N cetyl trimethyl ammonium bromide (CTAB) solution. (See "Standardization Procedure.")

Procedure—75 ml. of test sample was pipetted into the absorption cell. (Test samples containing 10, 15, and 20 ml. were used with the Evelyn instrument.) The cell was placed in the colorimeter, the stirrer started, and the galvanometer balanced to read zero.

For samples of unknown concentration a preliminary titration was made to determine the approximate amount of CTAB solution which would be required to reach the end point, as indicated by the maximum galvanometer reading (maximum turbidity of the solution in the cell).

Duplicate samples were titrated to maximum turbidity by adding from the buret approximately 75 per cent of the amount of CTAB solution required, followed by smaller and smaller portions as the end point was approached. The volume of the portions added near the end point was less than 2 per cent of the total amount required to reach the end point. Thus, when 5 ml. or more of CTAB was required, titration was to the nearest 0.1 ml.; when 3 to 5 ml. of CTAB was required, titration was to the nearest 0.05 ml., and so forth.

The galvanometer reading was assumed to be constant when no change in turbidity was registered over a one-half minute interval. The approximate time required for each determination was 20 min.

Experimental

Four series of tests were made to evaluate the turbidimetric titration method for the determination of surface active agents.

In the tests of Series A, the method was tried for the determination of anionic surface active agents in distilled water. The active ingredients of the commercial materials tested were sodium lauryl sulfate (Duponol C), sodium tetradecyl benzene sulfonate (Nacconol NR), and sodium oleyl methyl tauride (Igepon T). Sodium lauryl sulfate was tested in concentrations from 27 to 1,800 p.p.m., sodium tetradecyl benzene sulfonate from 10 to 100 p.p.m., and sodium oleyl methyl tauride from 20 to 300 p.p.m. The pH of all the solutions lay between pH 7 and pH 8. When the data for each material tested were plotted with the volume of CTAB to reach the end point as the ordinate and the concentration of surface active agent as the abscissa, the points fell in a straight line passing through the origin. As an example, points obtained in the titration of Nacconol NR are shown in Figure 1.

* Manufactured by Rubicon Co., Philadelphia, Pa.

† Manufactured by Photovolt Corp., New York, N. Y.

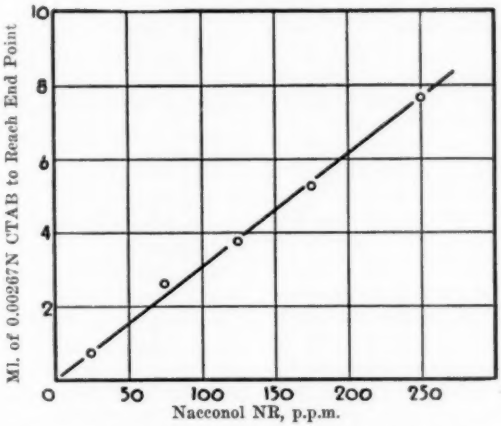

FIGURE 1.—Turbidimetric titration of Nacconol NR.

Tests of Series B were made to show the effect of change in pH on the results obtained with the turbidity titration method when titrating Nacconol NR. The tests were performed in neutral, acid, and alkaline solutions (pH 7.9, 1.6, and 10.5) at three concentrations (10, 50, and 100 p.p.m.) of the active ingredient, sodium tetradecyl benzene sulfonate. The results are given in Table I. The amount of CTAB required increases with increasing pH in the range tested.

The tests of Series C were made to show the effects of soaps on turbidimetric titrations. Sodium lauryl sulfate, sodium oleate, and mixtures of the two were titrated in neutral, acid, and basic solution, with the results shown in Table II.

TABLE I.—Effect of pH on the Turbidimetric Titration of Nacconol NR

Conc. STBS (p.p.m.)	Vol. CTAB[1] Required (ml.)		
	pH 1.6	pH 7.9	pH 10.5
10	0.58	0.67	0.84
50	3.28	3.70	3.88
100	7.05	7.65	8.0

[1] 0.00267N.

It was concluded that acidifying the solution is an effective way of ridding the solution of soap, although the titer is low compared to the titration of the Duponol C alone.

In Series D the effect of river water as a solvent on the titration of Duponol C was tested. River water, Duponol, and mixtures of the two were titrated in neutral solution.

It was thus shown that Duponol C and river water, singly or together, each required the same volume of CTAB to titrate.

Discussion of Results

The turbidimetric titration method was found to be satisfactory for the determination of surface active agents in

TABLE II.—Titration of Duponol C and Soap[1]

Agent	Vol. CTAB[2] Required (ml.)		
	Neutral	Basic	Acid
Sodium oleate	8.0	9.0	0
Duponol C	8.1	8.1	8.1
Duponol C and sodium oleate	14.0	16.0	7.0

[1] All solutions contain 0.1 g. per l. "as received" of each ingredient.
[2] 0.00267N.

TABLE III.—Titration of Duponol C [1] and River Water

Agent	Vol. CTAB [2] Required (ml.)
River water	2.5
Duponol C [1]	8.1
River water and Duponol C [1]	10.5

[1] 0.1 g. per liter.
[2] 0.00267N.

distilled water, which was the purpose for which it was originally developed by Lambert (3). The elimination of soaps by acidification was shown to be possible. However, it was found that the procedure, when a number of determinations were to be made, was time-consuming and that it was difficult to detect the end point at low turbidities. Also, it is not possible to make more than one determination at a time. The method requires that one have access to the colorimeter cell compartment for a stirrer and direct titration into the cell. The colorimeter which meets these requirements may not be available in all laboratories.

Two-Phase Titration Methods

Investigation

Two-phase dye-transfer titration methods for the determination of synthetic surface agents depend upon the difference in solubility of dyestuff-surface active agent complexes in water and in organic solvents. Acid dyestuffs, such as Pontamine Fast Red 8 BNL, form water-soluble complexes with anionic synthetic surface active agents, but form choloroform-soluble complexes with cationic agents. In the titration procedure used with acid dyestuffs, three parts of a solution of an anionic surface active agent were placed in a bottle with one part of chloroform. To the bottle was added 0.5 to 1.0 ml. of acid-dyestuff solution. The acid dyestuff remains in the water layer initially, leaving the chloroform layer colorless, but upon portion-wise addition from a buret of an equivalent amount of a cationic agent, with shaking of the bottle, the dyestuff begins to transfer to the chloroform layer. Upon addition of excess cationic agent the dyestuff transfers completely to the chloroform layer.

Basic dyestuffs, such as methylene blue, with anionic surface active agents form complexes which are soluble in chloroform and insoluble in water. In titration of anionic agents with basic dyestuffs, the color is initially in the chloroform layer. Upon addition of the cationic agent from a buret, with shaking of the bottle, the color transfers from the chloroform layer to the water layer. At the equivalence point the two layers are the same color. Further addition of cationic agent results in the removal of all color to the water layer.

Acid Dye Method

Scope—the acid dye method was used for determining surface active agents in distilled water, river water, sewage, and industrial wastes in the range of 4 to 1,000 p.p.m.

Apparatus—(a) Glass-stoppered bottles, 250-ml. (b) Microburet, 5-ml., calibrated in 0.01-ml. divisions. (c) Graduated cylinder, 25-ml. (d) Pipets, 50-, 25-, and 5-ml. (e) Buret, 50-ml., calibrated in 0.1-ml. divisions.

Reagents—(a) Acid dye, Pontamine Fast Red 8 BNL (E. I. du Pont de Nemours & Co., Inc.), 3 g. per liter in distilled water; Brilliant Blue FCF, 0.02 g. per 100 ml. (b) Cetyl trimethyl ammonium bromide, 1 g. per liter in distilled water. (See "Standardization Procedure.") (c) Chloroform, U.S.P.

Procedure—25 ml. of chloroform was added to a 250-ml. glass-stoppered bottle. Sample solution (75 ml.) was pipetted into the test bottle. In running determinations on known samples, an aliquot to give the desired amount of surface active agent was added to the bottle, and made up to 75 ml. with distilled water. Ten drops of dye solution were added to the bottle from a medi-

cine dropper. The contents of the bottle were mixed by inverting the bottle several times, and the pressure generated by the mixing of the phases was vented by cautiously removing the stopper.

The titration was carried out by adding portions of CTAB solution to the bottle until the end point was reached, which was indicated by a transfer of the dye from the top (water) layer to the bottom (chloroform) layer. After each addition of CTAB the phases were mixed by shaking the bottle back and forth by hand about 25 times. The force of shaking was adjusted by trial to give intimate mixing of the phases without causing excessive emulsification. After each shaking the phases were allowed to separate before further addition of CTAB solution.

The approximate amount of CTAB required for titration of unknown samples was determined by a preliminary titration. Duplicate determinations were then made by the addition of portions of CTAB to make 50, 75, and 90 per cent of the total amount required, followed by addition of 0.05-ml. increments until the end point was reached.

The time required for each determination varied from 3 to 15 min., depending on the time necessary for the phases to separate between additions of CTAB solution, and on the amount of surface active agent present in the sample.

Basic Dye Method

Scope—Same as for acid dyes.

Apparatus—Same as for acid dyes.

Reagents—0.1 per cent methylene blue, U.S.P., in distilled water; Safranine Y, 0.02 g. per 100 ml. The other reagents are the same as for the acid dye method.

Procedure—The procedure was the same as for the acid dye method with the following exceptions:

(a) 15 drops of dye solution were used.

(b) The end point was indicated by the equivalence in color of the two layers viewed by reflected light, instead of by the first transfer of color, as in the acid dye method. The color is initially in the bottom (chloroform) layer, from which there is a steady transfer of color during the course of the titration, until at the end point the color of the top and bottom layers is the same. The continued addition of CTAB solution past the end point results in further transfer of color until all the color is in the top (water) layer.

Modification of Method

The titration procedure used on the distilled and river water samples was found to be impractical with sewage because of the excessive emulsification, which resulted in excessive time for the phases to separate. Therefore, the sewage samples were run with 10 samples simultaneously to which increments of 0.1 ml. of CTAB solutions were added. Thus, only one phase separation was required of each sample and the end point could be determined by noting the bottle in which the dye had crossed the boundary.

Experimental

Various tests were made to evaluate the two-phase titration method. Its performance was tested with four different indicators, of which two were

TABLE IV.—Effect of Indicator Used on the Two-Phase Titration of Nacconol

Conc. of Nacconol (p.p.m.)	Vol. of CTAB[1] to Titrate (ml.)			
	Pontamine Red	Brilliant Blue	Methylene Blue	Safranine Y
100	3.05	2.90	2.94	3.03
70	2.15	2.05	2.03	2.10
40	1.30	1.15	1.15	1.20
10	0.40	0.30	0.25	0.25

[1] 0.00267N.

TABLE V.—Effect of pH on the Two-Phase Titration of Nacconol

pH	Vol. of CTAB[1] to Titrate (ml.)		
	100 P.P.M.	70 P.P.M.	40 P.P.M.
7.6	3.00	2.09	1.15
4.1	2.95	2.05	1.15
1.9	2.95	2.04	1.15

[1] 0.00267N.

basic dyes and two were acid dyes. The basic dyes used were methylene blue and Safranine Y; the acid dyes used were Pontamine Fast Red 8 BNL and Brilliant Blue FCF. The tests were made with sodium tetradecyl benzene sulfonate (Nacconol) as the active ingredient in the test solution. The results are given in Table IV.

The effect of pH on the two-phase titration of Nacconol, using methylene blue indicator, was tested at three levels of concentration (40, 70, and 100 p.p.m.) and three pH levels (1.9, 4.1, and 7.6). Table V gives the results of these tests.

Carbon tetrachloride was tried as the non-aqueous phase in place of chloroform. Two sets of tests were made with solutions of Nacconol from 10 to 100 p.p.m. Pontamine Fast Red 8 BNL was used in one set of tests and methylene blue was used in the other set (Table VI).

The possibility that dilute waste samples could be concentrated by boiling without affecting titration was investigated. A comparison of the results of titrating boiled and unboiled solutions of Nacconol is shown in Table VII.

Sodium oleate was selected as a typical soap for use in measuring the effect of soaps. Without acidification the soap in a soap-Nacconol solution titrates quantitatively. In order to differentiate between surface active agents and soap, the effect of the soap must be removed. This was done by the addition of concentrated hydrochloric acid, which precipitated the soap. The results are given in Table VIII.

A sample of river water was obtained and used as a solvent for Nacconol. The neutral solutions were titrated to find the effect of the river water at various concentrations. The results were compared with results from titration of samples in which distilled water had been used as a solvent (Table IX).

The two-phase titration method was tested with domestic sewage, containing industrial wastes, from the municipal sewage treatment plant at Columbus, Ohio. Tests were made on settled sewage without acidification, with acidification, and with 100 p.p.m. Nacconol added (Table X).

Standardization of CTAB Solution

Apparatus — Ordinary laboratory glassware and volumetric glassware as needed.

Reagents—(a) Cetyl trimethyl ammonium bromide (CTAB). (b) Po-

TABLE VI.—Effect of CCl_4 as Non-Aqueous Phase in Place of CCl_3

Indicator	Solvent	Vol. of CTAB[1] to Titrate (ml.)			
		100 P.P.M.	70 P.P.M.	40 P.P.M.	10 P.P.M.
PFR 8 BNL	CCl_3	2.93	2.00	1.10	0.35
	CCl_4	2.55	1.45	0.68	0.25
Methylene blue	CCl_3	2.94	2.03	1.15	0.25
	CCl_4	2.65	1.68	0.80	0.15

[1] 0.00267N.

tassium dichromate, cp, 0.1N solution. (c) Sodium thiosulfate, cp, 0.01N solution. (d) Potassium iodide, cp. (e) Sulfuric acid, cp, 1 volume in 10 volumes of water.

Test Solution—1 g. of cetyl trimethyl ammonium bromide was dissolved in distilled water in a beaker, then transferred to a 1-l. volumetric flask and made up to the mark with distilled water.

Procedure—With a pipet, 25 ml. of CTAB solution was measured into a 250-ml. Erlenmeyer flask. 50 ml. of 0.1N potassium dichromate solution was pipetted into the flask containing the CTAB sample, and the mixture, containing the cetyl trimethyl ammonium dichromate precipitate, was allowed to stand for 2 hr. The precipitate was filtered off through coarse filter paper to obtain the clear filtrate containing unreacted dichromate. To the filtrate was added approximately 5 g. of potassium iodide crystals dissolved in 20 ml. of water, followed by 2 ml. of 1:10 sulfuric acid solution. The sample was allowed to stand in the dark for 5 min., after which the liberated iodine was titrated to a starch end point with 0.01N sodium thiosulfate solution.

Calculations—

Volume of CTAB sample 50.00 ml.

Volume of 0.1N dichromate added 8.00 ml.

Volume of thiosulfate consumed (ml.):

Blank	I	80.65	
	II	80.43	Av. 80.54
Sample	I	39.90	
	II	40.20	Av. 40.17

Normality of thiosulfate from blank:

$$N_T = \frac{8.00 \times 0.100}{80.54} = 0.0099$$

	Volume Thiosulfate (ml.)
Blank	80.54
Sample	40.17
Difference	40.37

Volume of dichromate equivalent to 40.37 ml. of thiosulfate = Volume of dichromate consumed $= \frac{40.37 \times 0.0099}{0.100}$ = 4.01 ml. The normality of the dichromate solution relative to CTAB = 0.00333N.

The normality of the CTAB is

$$N_{CTAB} = \frac{V_D \times N_D}{V_{CTAB}} = \frac{4.01 \times 0.0333}{50.00} = 0.00267.$$

Mol. wt. of CTAB = 364.

If the CTAB was of 100 per cent purity the normality of a solution containing 1 g. per liter would be $\frac{1}{364} = 0.00275$N. Therefore, the apparent purity of the sample of CTAB, assuming that only CTAB and inert impurities are present, is $\frac{0.00267}{0.00275} \times 100 = 97$ per cent.

Discussion of Results

The tests on the effects of indicators showed that substantially the same results were obtained regardless of the indicator used, but that for use with industrial wastes and polluted waters acid dyestuffs, such as Pontamine Red and Brilliant Blue, are preferable. This is because the end point in a

TABLE VII.—Effect of Boiling on the Titration of Nacconol

Treatment	Vol. of CTAB[1] to Titrate (ml.)			
	100 P.P.M.	70 P.P.M.	40 P.P.M.	10 P.P.M.
Boiled 1 hr.	3.05	2.20	1.35	0.45
Unboiled	3.05	2.15	1.30	0.40

[1] 0.00267N.

TABLE VIII.—Elimination of Soap by Acidification

pH	Solution	Vol. of CTAB[1] to Titrate (ml.)			
		100 P.P.M.	70 P.P.M.	40 P.P.M.	10 P.P.M.
8.3	Nacconol and soap	5.9	3.75	2.05	0.40
1.6	Nacconol and soap	3.05	2.20	1.30	0.35
Neutral	Nacconol alone	3.05	2.15	1.30	0.40

[1] 0.00267N.

titration with acid dyes is marked by the first transfer of dye from the water layer to the chloroform layer, which is relatively easy to observe, compared to the end point with basic dyes, which is marked by the equality of color of the two layers viewed in reflected light. The probability that wastes will be both turbid and colored makes the matching of color layers with basic dyes difficult or impossible.

The fact that acid pH was found to have little effect on the results of two-phase titrations is desirable, since the precipitation of soap with hydrochloric acid was found to be an effective way of eliminating its effect on titrations.

Carbon tetrachloride was found to give low and non-linear titers, which was the basis for ruling it out as the non-aqueous solvent, since chloroform performed satisfactorily in the tests made. The results of the boiling and concentration-by-boiling tests showed that it is possible to concentrate a typical synthetic surface active agent without affecting the titer in the two-phase method. The test concentration was a four-fold one, from 5 to 20 p.p.m., but there is no reason to believe that higher concentrations could not be made for very dilute samples.

The indicator used for most of the tests was Pontamine Red, but the observation was made late in the test program that a somewhat sharper transfer of color was obtained with the acid dyestuff Brilliant Blue FCF, although the end results were essentially the same. The Brilliant Blue FCF also gave a desirably low blank (less than 0.05 ml.) in the limited number of tests in which it was used.

The titration of Nacconol added to river water was made to observe the effects on the test of the presence of various components of the river water, such as suspended solids and organic material dissolved from the vegetation along the river banks. The tests showed no indication of the presence of surface active agents in the river water.

It was felt that testing the method in such a medium as river water would show the effects, if any, of a large number of unknown constituents, other than surface active agents, which might be found in industrial wastes or polluted waters. The same idea prevailed

TABLE IX.—Effect of River Water as Solvent

Solvent	Vol. of CTAB[1] to Titrate (ml.)			
	100 P.P.M.	70 P.P.M.	40 P.P.M.	10 P.P.M.
River water	3.10	2.20	1.30	0.45
Distilled water	3.05	2.15	1.30	0.40

[1] 0.00267N.

TABLE X.—Titration of Columbus, Ohio, Sewage

Sample	Volume of 0.00267 N CTAB (ml.)
Settled Columbus sewage, neutral	0.55
Settled Columbus sewage, acid	0.40
Settled Columbus sewage plus 100 p.p.m. Nacconol	3.40
Nacconol alone, 100 p.p.m.	3.05

in the tests made on the addition of Nacconol to settled Columbus sewage: namely, the introduction of a large number of unknown constituents to the sample.

The emulsification in agitated sewage samples caused such a long delay in the separation of the phases that it was found that a single determination required 20 min. or more to complete. Therefore, 10 replicate samples were prepared at the same time and the titrant was added to each bottle in increments of 0.1 ml. to give total volumes of 0.1 to 1.0 ml., and the end point was determined by inspection after the separation of the phases. The time taken to prepare the extra samples was repaid in shorter total test time. Furthermore, emulsification completely obscured the end point in some trial runs using one sample, after several additions of titrant and shakings.

Other possibilities for interference with two-phase titrations besides those present in river water and sewage could be proposed. The CTAB reagent forms dichromate salts so that dichromates could be a source of interference. Inorganic salts have been shown to have little or no effect on dye transfer by some investigators, but it has been shown that sodium hexametaphosphate is not compatible with quaternary ammonium compounds such as cetyl trimethyl ammonium bromide. It has been found that a number of substances likely to appear in detergent formulations which do not react with CTAB include sodium carbonate, sodium sulfate, trisodium phosphate, tetrasodium phosphate, and borax.

Because the molecular species of the surface active material in an industrial waste or polluted water may not be known, as it is in laboratory "known" samples, it is necessary to report results of tests on such samples in terms of some one substance. A likely candidate for the choice is a surface active agent such as sodium tetradecyl benzene sulfonate, mol. wt. 376, which along with similar agents represents the most widely used type in the United States at present. Some British investigators have proposed reporting waste analysis results in terms of sodium alkyl sulfates of molecular weights averaging well below 300. However, the use of a molecular weight of at least 350 would seem to be a more logical choice in the United States. Approximately 2 p.p.m. variation from the mean may be expected with the two-phase method. This should not cause any more error than results from assuming that all surface active agents in an unknown waste are of one molecular species. The qualitative analysis of the waste mixture would be the only way to ascertain what agent is being determined.

Summary

Of the two determination methods selected and investigated, two-phase titration is the most suitable for determination of anionic surface active agents in industrial wastes and polluted waters. The desirable points, such as elimination of soaps, feasibility of concentration by boiling, simplicity of procedure, independence from pH effects, rapidity of determinations, and simplicity of apparatus, recommend the two-phase titration over the turbidimetric method. The testing done in river water and sewage gave an indication of satisfactory performance in the presence of a number of organic substances.

Although the number of agents tested in the present investigation was small, it seems safe to conclude from the results of the investigations made that information obtained with one or a few anionic surface active agents of chain lengths C_{10} to C_{18}, or their equivalent, may be safely extended to include most of the important members of the class.

Tests of the two-phase method under different conditions of laboratory and analyst would be useful in evaluating its reliability.

Further testing of Brilliant Blue FCF as an indicator is also recommended.

Acknowledgment

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COMMUNITY-WIDE INSTALLATION OF HOUSEHOLD GARBAGE GRINDERS

Under the above heading, the U. S. Public Health Service has published a 41-page progress report on the effects of community-wide installation of household garbage grinders on environmental sanitation of a community. Jasper, Ind., is the city reported on, for the period March, 1950 to October, 1951.

The report, prepared jointly by representatives of the Indiana State Board of Health and the U. S. Public Health Service, covers the effects of the installation on such factors as water consumption, the sewer system, raw sewage characteristics, sewage treatment plant operation, refuse collection and disposal, fly densities, rodent infestation, and morbidity and mortality trends.

The report, as Public Health Service Publication No. 24, is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at the price of $0.20 per copy.

CONTROL OF SEWAGE CHLORINATION BY AMPEROMETRIC TITRATION *

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The Orange County Joint Outfall Sewer is owned by and serves eight communities: the cities of Anaheim, Fullerton, Orange, and Santa Ana, and the Sanitary Districts of Buena Park, Garden Grove, La Habra, and Placentia. The connected population is currently estimated to be in the neighborhood of 125,000. The treatment works, designed for an average flow of 10.2 m.g.d., is located 6 mi. southwest of Santa Ana and provides primary treatment only. The average daily flow is now in excess of the design capacity, frequently exceeding 14 m.g.d. on peak days during the summer. The proportion of industrial wastes is high, particularly of wastes from citrus processing plants and canneries. Consequently, the sewage is strong. Table I gives the monthly average characteristics of the plant effluent for the four months covered by this discussion.

The data given in Table I are based on 24-hr. composite samples collected proportional to flow by automatic sampling devices, and taken every other day. The average strength is affected by the relatively weak Sunday sewage, and it is possible to pick out of the records peak days which exceed the average by as much as 50 per cent.

The effluent of the treatment plant is discharged to the Pacific Ocean through an outfall line 4.99 mi. in length. The submarine portion of the outfall is 3,100 ft. long and terminates in water approximately 35 ft. deep.

About 0.5 mi. from the end of the land portion of the outfall line the effluent of a primary treatment plant operated by the City of Newport Beach enters the outfall line. This effluent is not of extreme strength, although the sulfide content is rather high. The volume averages about 2.5 m.g.d.

Chlorination Station

The effluent chlorination station of the Joint Outfall Sewer was put in operation in September, 1948. It is located on the beach, at the junction of the land and marine sections of the outfall line. Its equipment includes three 6,000-lb. chlorinators and two 2,000-lb. chlorinators, with evaporators and appurtenances. Chlorine is received in 30-ton tank cars. The chlorine solution lines enter the outfall line through a manhole and are extended about 20 ft. downstream. Through this manhole a hose line enters the outfall line and is extended 300 ft. downstream. Chlorinated sewage is drawn back through this hose line by a small pump to provide samples for residual chlorine control. Tests have shown that mixing is complete at this point, and the contact time is about 5 min. The entire marine portion of the outfall line serves as a chlorine contact tank, and tests have

TABLE I.—Monthly Average Characteristics of Clarified Sewage, Orange County, Calif.

Month (1951)	Susp. Sol. (p.p.m.)	B.O.D. (p.p.m.)
June	158	582
July	170	659
August	221	857
September	206	773

* Presented at 1952 Annual Meeting, California Sewage and Industrial Wastes Assn.; Santa Cruz, Calif.; Apr. 23–26, 1952.

shown the average chlorine contact time to be about 45 min.

The station staff, in addition to strictly operating and maintenance duties, make residual chlorine tests as often as necessary to hold the residual value within the prescribed limits, and also make tests for total sulfides at 2-hr. intervals. A detailed log of station operation is kept. Operation of the chlorination station is complicated by the fact that there is no provision for measuring the flow at this point. It is further complicated by the fact that there is an automatically controlled booster pumping station on the outfall line which produces sudden and sometimes rather large variations in the rate of flow.

The chlorination station is operated during that portion of the year when there is recreational use of the beaches in the vicinity, since its function is to protect the surf waters from contamination. This means full-time operation from about the first of June to the middle of October, with week-end and holiday operation before and after that period whenever the weather appears to be favorable for beach use.

Surveys conducted by the State and County Health Departments, and by the Joint Outfall Sewer, have shown that contamination from unchlorinated sewage from the outfall can affect the quality of the water along about 28,000 ft. of beach. As a part of the control program, the Joint Outfall Sewer laboratory examines samples from 11 sampling stations along this length of beach twice each day through the week and once on Saturday. The County Health Department also takes samples, although less frequently.

The foregoing, although a digression from the main purpose of this discussion, is necessary to provide the background of the problem in chlorine control. The solution reported here may not be of general application, but should serve as a starting point for similar work in other plants.

Sampling Procedures

From data to be presented later it is apparent that chlorine usage was extremely high, averaging in excess of 75 p.p.m. over a 4-month period (June through September, 1950, for example). Certain data accumulated during the regular control work led to the conclusion that other methods of controlling chlorine dosage than the conventional ortho-tolidine test might aid in securing some reduction in chlorine usage.

Over a period of about two years, samples were taken at irregular intervals of the chlorinated effluent at various residual chlorine levels as shown by the ortho-tolidine test and examined to estimate the most probable number of coliform organisms remaining after 45-min. contact. The results of this series of samples are shown in Table II. While it would have been desirable to have more samples, and to make a statistical analysis of the results, the conclusion that there is little, if any, relation between the ortho-tolidine residual chlorine content and the residual number of organisms, appears to be obvious. Further, there were occasional samples showing no residual chlorine, by the ortho-tolidine test, yet showing marked bacterial reduction. It is suggested that the explanation of these facts must be that all, or nearly all, of the bacterial kill to be had is obtained before the ortho-tolidine residual level is reached, and that variation in the numbers of residual organisms is due either to random distribution or the inherent inexactness of the most probable number

TABLE II.—M.P.N. *E. coli* per Ml. in Chlorinated Effluent at Various Residuals

O-T Res. (p.p.m.)	No. of Samples	M.P.N. Less Than 1.8		M.P.N. Less Than 1,000	
		No.	%	No.	%
0.0	5	0	0	2	40
0.2–0.3	8	4	50	8	100
0.4–0.5	10	4	50	10	100
0.6–0.7	16	8	50	16	100
0.8–1.0	5	5	100	5	100

system of interpreting fermentation tube results.

In the examination of the samples in this series, at least three, and usually more, decimal dilutions were made, with five tubes being inoculated at each dilution. These tests, unfortunately, were presumptive only.

Laboratory Study

This series of samples was followed by a laboratory study of the effect of chlorine dosages too small to produce an ortho-tolidine reaction. The procedure was to divide a sample of effluent into a series of portions, usually 200 ml. each. After estimating the chlorine demand, dosages of chlorine amounting to 25, 50, 75, and 100 per cent of the chlorine demand were applied. After thorough mixing the portions were allowed to stand for the desired contact period of 45 min. At the end of that time, a series of decimal dilutions was made and inoculated into lactose broth. At least three dilutions were made for each portion, and usually more. Five tubes were inoculated at each dilution. Brilliant-green bile was used for confirmation of positive presumptive tubes.

Presentation of the results of this study in detail is beyond the scope of the present paper. It is sufficient to say that marked bacterial reduction was found where the chlorine dosage was below the level of the ortho-tolidine reaction. Actually, there is nothing new in the idea that effective disinfection of sewage can be secured by chlorine dosages which will not produce an ortho-tolidine reaction. Results reported as long ago as 1927 by Tiedeman (1), and later by Rudolfs and Ziemba (2), Beardsley (3), and others, have all amply demonstrated this fact. But in the absence of a suitable control procedure, it was not practical to operate below the ortho-tolidine level.

A series of reports by Marks, Joiner, and their co-workers (4)(5)(6) have shown that chlorine residuals could be measured by titration in acid solution with a standard solution of phenylarsene oxide, and that the residuals so measured were higher than indicated by ortho-tolidine on the same samples. In other words, this procedure is capable of measuring residuals below the point at which the ortho-tolidine reaction begins, and consequently provides a method for controlling what has come to be called sub-residual chlorination. This procedure has been quite widely applied in controlling the chlorination of water, and may be modified so as to allow differentiation between combined and free residual chlorine.

The procedure may be used as an ordinary titration, using starch indicator, or the end point may be indicated electrically, for which instruments are available.

This procedure, however, is not applicable to sewage because of side reactions. A modified procedure, where an excess of phenylarsene oxide reagent is added to the sample and then back-titrated with standard iodine solution, is applicable to sewage. On account of the interference from color and turbidity, the amperometric titration is to be preferred to titration with starch indicator. This is particularly true where tests are to be made by non-technically trained operators rather than by laboratory personnel. Standard potassium iodate solution, as suggested by Nusbaum and Meyerson (8), has been found to be much more stable than standard iodine solution, and also much easier to prepare. Work now in progress in the Joint Outfall Sewer laboratory appears to indicate that standard sodium thiosulfate solution works equally as well as the phenylarsene oxide solution, and may be preferred because of lower cost and greater ease of preparation.

A laboratory investigation was made of the bacterial effectiveness of chlorine dosages which could be measured by amperometric titration, but which were below the level of ortho-tolidine reac-

tion. The procedure was similar to that previously outlined. Again, it is not necessary to give the results in detail. They followed quite closely those reported by Marks, Joiner, and Strandskov (4), and may be summarized as showing that adequate disinfection could be secured by chlorine dosages below the amount required to give any reaction with ortho-tolidine, and that these dosages gave residuals which could be measured for control purposes by amperometric titration. These results do not agree with the conclusions drawn by Heukelekian and Day (7), although their conclusions do not seem to be supported by their data, as has been pointed out by Nusbaum and Meyerson (8).

Plant Application

After study of these laboratory results, a plant-scale test was made during a 10-day period in March, 1951. The results of this test were evaluated by repeated series of samples of the surf waters, by bacterial examination of samples of the chlorinated effluent, and by comparison of chlorine usage with that for a similar period during the previous year. It was concluded that amperometric titration was an entirely practical control procedure, that the beaches were as well protected when this method of chlorine dosage was employed, and that there would be some economy in chlorine consumption. Consequently, amperometric titration was used for the routine control of chlorination during the entire 1951 season.

To simplify the operation, residuals were recorded to the nearest 0.5 p.p.m. only, except when the residual was less than 0.5 p.p.m., when it was recorded to the nearest 0.1 p.p.m. The laboratory studies had indicated that, with a 45-min. contact period, a residual of 2.5 p.p.m., measured amperometrically, would produce adequate disinfection.

One full season's experience with this method of controlling chlorine dosage has fully substantiated the conclusions drawn from the laboratory and the 10-day plant-scale tests. The procedure is entirely practical, even for use by non-technically trained personnel. There is no interference by color or turbidity, and the end point is sharp and definite. The time required for the test may be slightly longer than for the ortho-tolidine test, and the reagents are more expensive and require more time for preparation. These are of minor importance.

TABLE III.—Comparison of Quality of Surf Water

Year	Number of Samples	M.P.N. Exceeding 10 per Ml	
		No.	%
1950	1,849	172	9.30
1951	1,962	82	4.18

TABLE IV.—M.P.N. *E. coli* per Ml. in Chlorinated Effluent at Various Residuals

Amper. Res. (p.p.m.)	No. of Samples	M.P.N. Over 1,000		M.P.N. Over 100	
		No.	%	No.	%
(*a*) Experimental Results					
<0.5	26	23	88.3	25	96
0.5	10	5	50	7	70
1.0	10	3	30	7	70
1.5	19	6	31.6	8	42.1
2.0	9	0	0	0	0
2.5	13	1	7.7	3	23.1
3.0	14	0	0	0	0
3.5	10	0	0	2	20
4.0	11	1	9.1	1	9.1
4.5	17	0	0	0	0
5.0	9	0	0	0	0
(*b*) Regrouped Results					
0.0–2.0	65	40	61.5	47	72.3
2.0–4.5	74	2	2.7	6	8.1

Effect on Beaches

To evaluate the degree of protection given the bathing beaches, Table III presents a comparison of the results obtained during the 4-month period June through September, 1951, when all chlorination was controlled by am-

perometric titration, with those for the same four months of 1950, when ortho-tolidine control was used. While there is no official standard for the quality of water on bathing beaches in California, there is a generally accepted working standard which provides that not more than 20 per cent of the samples should have an M.P.N. of coliform organisms in excess of 10 per ml., when 20 samples or more are examined per month.

During 1950, in order to reduce chlorine consumption, chlorination was suspended at times when ocean currents were in a direction to carry the effluent out to sea, thus preventing contamination of the surf waters. During 1951, chlorination was continuous except for minor interruptions due to mechanical or electrical failures. Hence these data show that the surf waters were as well protected in 1951 as in 1950, but not necessarily better, as a superficial examination might indicate. The lower incidence of samples having an M.P.N. in excess of 10 was due to more nearly continuous operation.

During the 4-month period under consideration a series of samples of chlorinated effluent was examined to determine the numbers of coliform organisms remaining after 45-min. contact. The results are shown in Table IV(*a*). At least three, and usually more, decimal dilutions were made. In most cases five tubes were inoculated at each dilution. Brilliant-green bile was used for confirmation of positive presumptive tubes during most of the season, although during the latter part of the period E.M.B. agar was used on a part of the samples. In this series, no sample having a residual of less than 5 p.p.m. by amperometric titration showed any residual by ortho-tolidine.

In the absence of a statistical analysis of these data, they have been regrouped by inspection, as shown in Table IV(*b*). It appears that adequate disinfection will be obtained after 45-min. contact by an amperometric residual of 2.0 p.p.m., which is slightly lower than the 2.5 p.p.m. indicated by the laboratory study. Actually, under operating conditions it is not possible to hold the residual within as close limits as might be desired. Experience indicates that if residual tests are made at least three times per hour, and the chlorine dosage adjusted so that the daily average residual is 3.0 p.p.m., the end results will be satisfactory.

It will be noted that no consideration has been given to the percentage reduction in the M.P.N. of coliform organisms. In a case of this sort, where the M.P.N. of the surf waters must be held below a certain point, it is not the percentage of organisms killed which is significant, but the actual number of organisms escaping. Samples of the unchlorinated effluent have had an M.P.N. ranging downward from 6,000,000 or 7,000,000 per ml. Samples taken from the surf waters over considerable periods when the effluent was not chlorinated have only on very rare occasions had an M.P.N. in excess of 700 per ml. This indicates that the degree of dilution afforded is quite great, generally at least 10,000 times. If under the most unfavorable conditions the dilution should be as little as 1,000 times, and the M.P.N. in the chlorinated effluent does not exceed 1,000 per ml., then the surf waters should generally not have an M.P.N. in excess of 1 per ml. It is suggested that the data in Table IV(*b*) may be interpreted as meaning that a residual chlorine content in the effluent of 2.0 p.p.m. (measured by amperometric titration) will produce a final coliform content which will be below 1,000 per ml. 97.3 per cent of the time, and less than 100 per ml. 91.9 per cent of the time. The data summarized in Table III show that the degree of disinfection so attained has been adequate for protection of the bathing beaches.

In evaluating the results of controlling chlorine dosage by amperometric titration, and continuously operating at dosages less than would be required to give an ortho-tolidine reaction, it becomes desirable to estimate the reduc-

TABLE V.—Comparison of Chlorine Usage June through September, 1950 and 1951

Item	1950	1951	Increase or Decrease (%)
Volume treated (m.g.)	1,762	1,908	+ 8.29
Chlorine used (lb.)	1,144,146	1,074,054	− 6.13
Hours of operation	2,353.5	2,711.25	+15.20
Total sulfide (p.p.m.)[1]	4.75	4.65	− 2.11
5-day B.O.D. (p.p.m.)[1]	500	577	+15.40
Chlorine charged to sulfides (lb.)[2]	489,897	621,360	+24.55
Chlorine charged to chlorine demand (lb.)	645,249	542,694	−29.84
5-day B.O.D. (tons)	3,675.9	4,594.7	+24.99
Chlorine per ton B.O.D. (lb.)	175.5	98.5	−43.88

[1] Weighted average, Joint Outfall Sewer and Newport effluents.
[2] On basis of 9 lb. chlorine per pound sulfide S" (9).

tion in chlorine usage. Such estimation is difficult, because the sewage treated in one period is different from that in another in both volume and strength. Some pertinent information regarding sewage volumes and strengths, and the amounts of chlorine used, for the 4-month period June through September, 1951, as compared to the same four months of 1950, are presented in Table V.

Although the use of pounds of chlorine per ton of 5-day B.O.D. as a unit figure may be questioned as to absolute validity, there is beyond doubt some relation between chlorine demand and the strength of sewage as measured by B.O.D., and the records of the Joint Outfall Sewer indicate that comparisons made on this basis have relative accuracy. Using this unit value, it appears that if chlorine had been used at the same rate during 1951 as it was during 1950 (175.5 lb. per ton of 5-day B.O.D.) the chlorine usage during 1951 would have been greater by 353,700 lb. If the use of this value is totally unjustified, there still remains the fact that 146 m.g. more sewage were disinfected with 70,000 less pounds of chlorine, and at the same time the bathing beaches were adequately protected.

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REMOVAL OF CARBON DIOXIDE FROM DIGESTER GAS *

By James E. Frook

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The basis for this paper is an investigation made by the laboratory of the Toledo, Ohio, sewage treatment plant to determine the feasibility of scrubbing carbon dioxide from the plant digester gas at relatively low pressure.

Expansion plans for the plant specify two Hortonspheres capable of jointly delivering 194,000 cu. ft. of gas from a pressure of 29 p.s.i. Since expected average daily production of gas will be 350,000 to 400,000 cu. ft., it is obvious that even this storage capacity is rather limited. Included in the expansion plans are four compressors set to maintain gas storage pressure at 29 p.s.i., consisting of two of 400-c.f.m. and two of 500-c.f.m. capacity.

The purpose of the gas storage is to provide a more even gas flow to the gas and dual-fuel engines in the present and expanded plant by absorbing the surges in supply and demand. It is not economically sound to provide more storage, as fuel oil storage for the dual-fuel engines is less expensive and more practical.

However, one method of increasing the gas reservoir capacity without increasing the size would be to remove any inert portion of the gas. Specifically, this substance is carbon dioxide, which constitutes one-third of the gas by volume.

Removal of the carbon dioxide in sewage plant digester gas is not an original idea, and it has had practical applications. There has been thought on the subject in this country, though it has remained for Europeans to exploit the possibilities on a plant scale (1) (2) (3). Fuel shortages have produced gas scrubbing installations both in England and on the Continent. However, not only have these plants compressed and scrubbed the gas, but the process has been carried on to a liquefaction at pressures of 5,000 p.s.i. The resultant fuel, nearly pure methane, was suitable for portable fuel tanks in automotive vehicles. Needless to say, conventional fuels must be extremely scarce or costly to warrant such an installation.

Although there were some data on plants of the aforementioned type, no information could be found on scrubbers employing low pressure. To obtain more definite information concerning gas and water flows, scrubber capacities, and pressure effects, a laboratory-size scrubber tower was constructed.

Apparatus

A used home hot water tank of 30-gal. capacity was remodeled. A number of taps were made into the tank so that various levels in the tank could be controlled by use of a gage glass. Gas and water inlets and outlets were provided, a pressure gage, an entrance hatch, and sundry valves (Figure 1). The interior was packed with coke as a dispersing medium. Water passed down the surface of the coke in counter flow to the current of rising gas.

Gas flow was maintained by utilizing the compressor from a walk-in cooler

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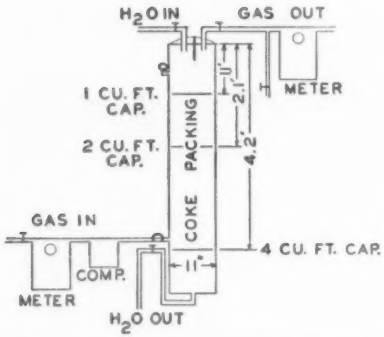

FIGURE 1.—Schematic layout of low-pressure carbon dioxide scrubber.

refrigeration unit. Metering of gas flows was done by two 5- to 150-cu. ft. per hr. dry gas meters, one on the gas inlet line and the other after release from the scrubber tank. To protect the inlet meter, a check valve was installed in the line. Carbon dioxide determinations were made with an Orsat apparatus. Scrubber capacities hereafter mentioned are total capacity and include the volume occupied by the coke.

Procedure

The inlet and outlet gas meters were checked against each other, and necessary corrections in the data were made to compensate for this error. Also, although the compressor would deliver 1 c.f.m. of gas at atmospheric pressure, there was a decrease in flow against pressure, as follows:

29 p.s.i.	0.98 c.f.m.
40 p.s.i.	0.95 c.f.m.
45 p.s.i.	0.92 c.f.m.

Corrections for this flow decrease were made in the experimental data.

The previously mentioned pressures were selected because the 29-p.s.i. value is the specified working pressure for the compressors supplying the gas holders, the 45-p.s.i. value derives from apparatus limitations, and the 40-p.s.i. value gave a point between the other two.

Water flow was found by running the water outlet line into a calibrated container. Average water temperature was 5° C.

When starting a run, the scrubber was stabilized by maintaining a set wash-water flow and by holding steady the pressure and water levels. Not until this stabilization was effected were data recorded. Conditions during the data collection phase were held as uniform as possible, before average values were obtained. Runs were of 30-min. duration, with five carbon dioxide analyses and three water flow measurements.

Discussion

Effect of Pressure

Pressure, in the relatively low ranges of the experiment, was not as great in its effect as had been supposed. With 1-cu. ft. capacity, it was hardly noticeable, and only in the 2- and 4-cu. ft. capacities was it of consequence. Even though there was more of a spread in the higher capacities, the rate of effect was no greater. It would seem that a pressure of about 105 p.s.i. would be required to remove completely all carbon dioxide at water flow of 2.5 g.p.m. average and at the experimental capacities.

Effect of Wash-Water Flow

Smaller flows of wash water were more efficient at removing carbon dioxide than were larger ones, as is shown by the flattening out of the absorption curves (Figures 2, 3, and 4) past flows of 4 to 5 g.p.m., and were more pronounced with increased capacity. The rule of thumb that several small amounts of water will wash better than one large amount totaling the same seems true here.

Effect of Capacity

Capacities used were 1, 2, and 4 cu. ft. for a corrected gas flow of 1 c.f.m. Results on increasing capacity were readily apparent and indicated a greater effect on scrubbing action.

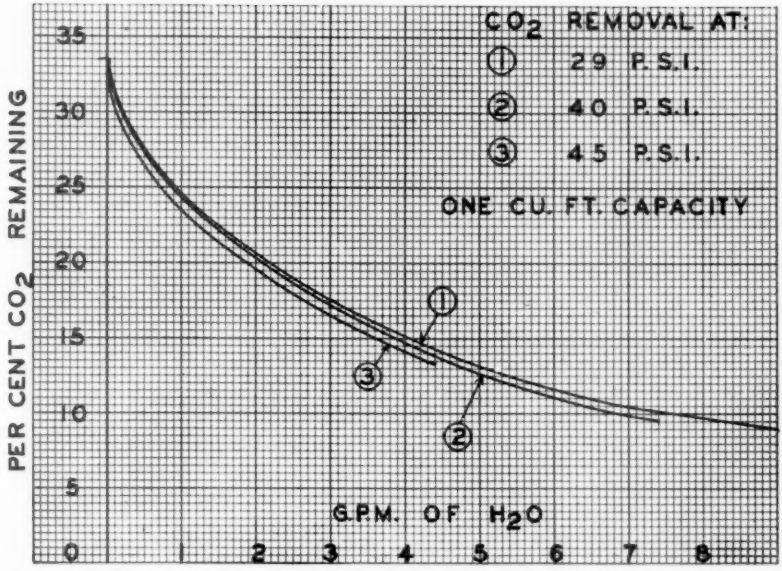

FIGURE 2.—Absorption curves for carbon dioxide removal; scrubber capacity, 1 cu. ft.

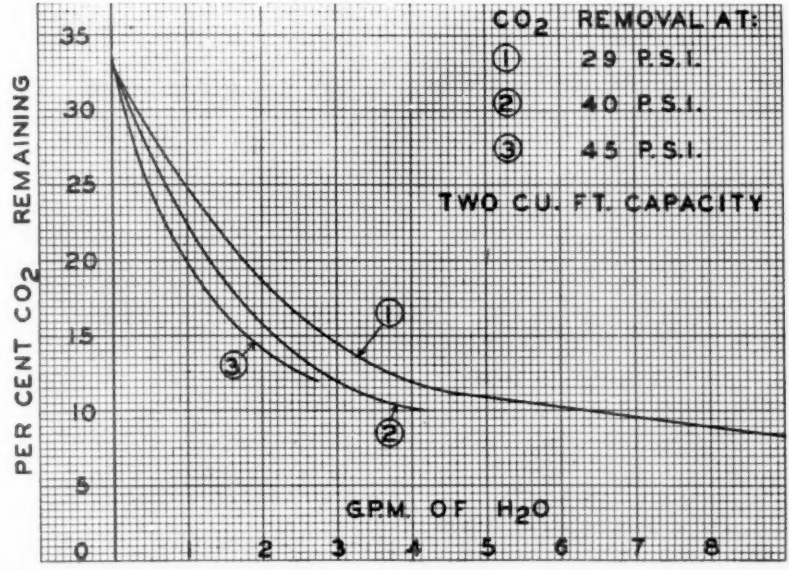

FIGURE 3.—Absorption curves for carbon dioxide removal; scrubber capacity, 2 cu. ft.

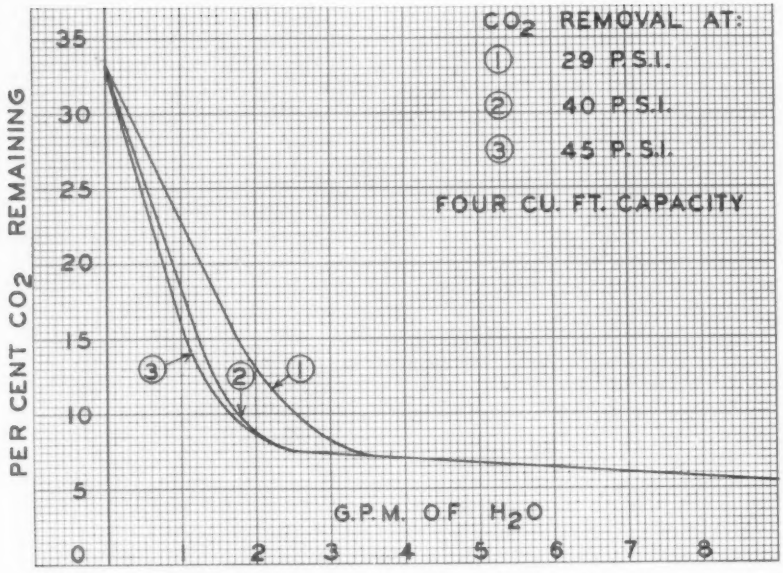

FIGURE 4.—Absorption curves for carbon dioxide removal; scrubber capacity, 4 cu. ft.

Based on an average water flow of 2.5 g.p.m., about 8 cu. ft. of capacity for each cubic foot of gas per minute would be needed to completely remove the carbon dioxide at the experimental pressures.

Effect of Gas Quantity

The amount of gas passing the scrubber decreased with increasing water flows. From calculations it was determined that considerable methane was being lost, in addition to carbon dioxide absorption. The percentage of methane lost was low with low water flows, and increased with greater flows as, of course, was true of the carbon dioxide absorption.

By setting up a ratio of per cent methane absorbed to per cent of carbon dioxide absorbed (that is, in per cent of total gas volume), fairly uniform results are found in the low water flows. In higher flows, however, there was an increase in the decimal ratio value, indicating that more methane was being absorbed, proportionally, than had been at lower water flows. A summary of these ratios before any regular increase began, is as follows:

Pressure (p. s. i.)	Scrubber Capacity (cu. ft.)		
	1	2	4
29	0.43	0.21	0.22
40	0.39	0.24	0.18
45	0.73	0.29	0.16

Study of these values shows that with increasing capacity and pressure the methane-carbon dioxide absorption ratio decreases and that methane losses are reduced to near minimum. This, of course, is a reflection of more efficient carbon dioxide removal and points to the need for higher pressures for effective and economical action. Increase in the decimal ratio at higher water flows, lower pressures, and smaller capacities may be due to a physical "drag-out" of the methane.

Conclusions

1. Gas and water flows, pressure, and capacity are critical variables in

scrubbing carbon dioxide from digester gas.

2. With a gas flow of 1 c.f.m., a scrubber of 4-cu. ft. capacity, water flows of up to 9.4 g.p.m., and pressures of 45 p.s.i., it is possible to remove 81.4 per cent (27.2 per cent by volume) of the carbon dioxide present in a digester gas 33.4 per cent by volume.

3. Most efficient use of wash water is obtained with low flows and high scrubber capacity. A series of small in-line scrubbers using low wash-water flows would make more use out of the absorptive action of the water than would a single large scrubber with one-pass wash water.

4. From the average of the three pressures used, after 1 cu. ft. of capacity, each additional cubic foot of capacity would increase carbon dioxide removal by 7.7 per cent of total carbon dioxide present. From the average of the three capacities, after 29-p.s.i. pressure, each additional pound of pressure would remove 0.69 per cent more of the total carbon dioxide present.

5. Methane is absorbed in a definite proportion to the carbon dioxide. It is only in the higher water flows and lower capacities and pressures that methane losses become disproportionate, indicating lower general scrubbing efficiency and probable carryover of the methane.

Summary

Low-pressure removal of carbon dioxide from sewage plant digester gas to increase limited storage capacities is not economically feasible. Excessive water requirements and the need of several scrubbing towers would mean extensive plant installations. Considerable methane would be lost in the process, and the cost of power for water pumps would be a deterring factor.

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RATES AND RATE STRUCTURES REPORT STILL AVAILABLE

A few reprints of "Fundamental Considerations in Rates and Rate Structures for Water and Sewage Works" are still available from the Federation headquarters office. The 126-page report—a joint effort of committees representing technical, legal, municipal management, and banking interests—reviews the factors involved in financing privately-owned and publicly-owned utilities, and recommends procedures for establishing fair rates and rate structures.

Reprints are available at $1.00 per copy from Federation of Sewage and Industrial Wastes Associations, 325 Illinois Building, Champaign, Illinois.

Industrial Wastes

RENDERING PLANT WASTE TREATMENT STUDIES

II. Pilot Plant Investigations

By Marvin L. Granstrom

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In a previous paper (1) the writer described the manufacturing processes of the rendering industry and the types of wastes discharged therefrom. To review briefly, dead animals and parts of dead animals are rendered with recovery of hides, grease, and high-protein animal feed. To keep working conditions tolerable and to reduce odors, good housekeeping is essential. The trucks, barrels, and floors are washed after each use or operation. These wastes are greasy, black, septic, and smelly; due to the state of partial decomposition of the raw material, most of the organic matter is in the colloidal or dissolved form. The waste is quite strong, the 5-day 20° C. B.O.D. varying from 500 to 10,000 p.p.m. and total solids up to 10,000 p.p.m. It is quite possible that some of the animals were diseased, so the wash waters may contain organisms parasitic to both man and animals such as. *Trichinella spiralis* (trichinosis) and *Cysticercus bovis* (beef tapeworm) among the animal parasites, and *Brucella* organisms (brucellosis) and *Salmonella* organisms (salmonellosis) among the plant parasites. If the receiving watercourse is to be used in some manner for humans or stock, the health hazards should be seriously considered in the question of treatment requirements.

This paper and the previous one discuss the findings of such treatment processes as: chemical treatment using alum and chlorine with and without acid for pH control; air flocculation with and without alum; trickling filter pilot plant with such treatment aids as recirculation, aeration, and effluent chlorination; anaerobic fermentation of the total waste; and sludge drying properties before and after observed digestion.

Conduct and Results of Investigations

Because most detached rendering plants are located outside the areas served by municipal sewers, if treatment of the wastes is necessary it must be done by the industry. Most plants are small, so that the treatment process should be as inexpensive and simple as possible. All tests herein described were performed on samples taken of the effluent from the grease removal tank. All B.O.D.'s indicated herein refer to the 5-day 20° C. values.

Chemical Treatment

Chemical treatment was the first method tried. The most effective chemicals were found to be a filter alum and chlorine. Figure 1 substantiates previously reported findings; that is, the combination is successful providing sufficient chlorine is used. Each of the two samples S1 and S2 was treated with various combinations of chlorine and alum doses. After the chemicals were added the samples were violently mixed for 2 min. followed by 30 min. slow flocculation, at which time the samples were removed from the stirrer and allowed to settle for 1 hr. Portions were

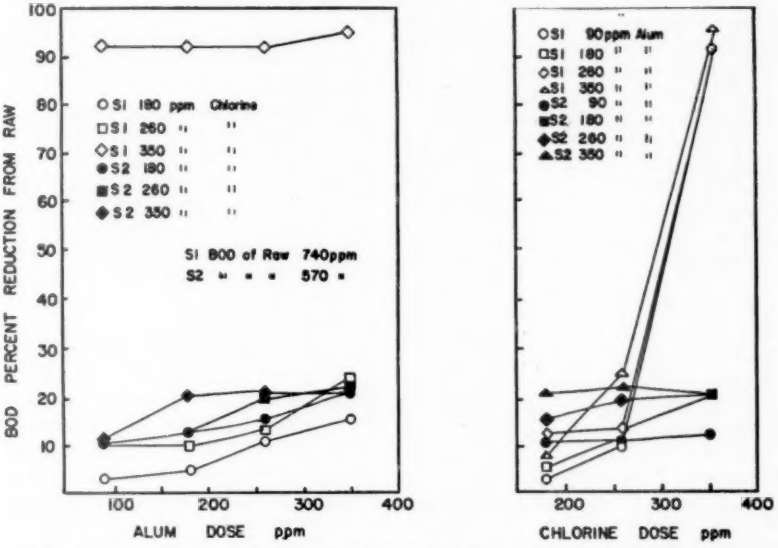

FIGURE 1.—Effect of alum and chlorine on B.O.D. reduction in rendering waste.

removed from about halfway down with a pipet. The left-hand plot in Figure 1 shows that increasing the alum dose above 80 p.p.m. was of little consequence in removal of B.O.D. on either sample (the bicarbonate alkalinity of the waste was about 415 p.p.m.) The right-hand plot shows that in the case of sample S1 somewhere between 260 and 350 p.p.m. chlorine, a very sharp increase of B.O.D. reduction is noted; however, 350 p.p.m. chlorine was insufficient to reduce the B.O.D. a significant amount on sample S2. It may be supposed, from this and other observations, that a similarly sharp increase in B.O.D. reduction on S2 would be observed if the chlorine dose were adequate. On none of the 15 or 20 samples treated by chlorine during the total investigation was there any chlorine residual after 15 min., even with doses of 350 p.p.m. The color, with doses as low as 100 p.p.m., was greatly reduced and it may be concluded that considerable disinfection was accomplished.

Aeration

Aeration or air flocculation with or without alum was tried on a laboratory-scale investigation. One liter of sample was gently aerated using a laboratory-type ball diffuser; when alum was used it was added toward the end of the designated aeration period and aeration was continued until a good floc was evident. The aerator was removed and the sample allowed to remain quiescent for 1 hr., at which time samples were carefully withdrawn by a pipet from about halfway down. Figure 2 shows that if any benefit from aeration with or without alum was accomplished, a 10-min. period was as effective as a 4-hr. period. On sample S1 the values for total solids, volatile solids, and B.O.D. on the raw sample were 2,090, 1,260, and 1,510 p.p.m., respectively, with no alum used; the aeration changed the removal from straight settling from about 32 to 40 per cent, 32 to 50 per cent, and 24 to 18 per cent. On sample S2, in which the values for total solids and volatile solids of the

raw were 9,560 and 8,420 p.p.m., alum only with no aeration changed the values of removal compared to straight settling from 43 to 56 per cent and 48 to 63 per cent, respectively; aeration and alum changed the removals from 43 to 66 per cent and 48 to 71 per cent. The B.O.D.'s are not available on S2 because dilutions for the laboratory analysis were inadequate. On sample S3, in which the total solids, volatile solids, and B.O.D. values for the raw were 2,080, 1,700, and 1,060 p.p.m., straight settling accomplished 24, 32, and 69 per cent removals; alum with no aeration, 34, 51, and 84 per cent removals; aeration with no alum, 25, 35, and 65 per cent removals; and alum plus aeration, 35, 51, and 76 per cent removals. Sample S4 with values for the raw of 1,750, 1,130, and 750 p.p.m. for the total solids, volatile solids, and B.O.D. gave removals as follows: straight settling, 5, 12, and 21 per cent; alum with no aeration, 15, 29, and 30 per cent; aeration with no alum, 22, 0, and 23 per cent; and alum plus aeration, 12, 15, and 32 per cent.

Trickling Filter

A trickling filter pilot plant was constructed to determine if the waste was amenable to that type of treatment. During the spring and early summer of 1951, it was operated as a straight recirculating trickling filter with the two filters in parallel. For the operation during the same period of 1952 it was converted to two parallel plants, one using aeration and the other not (Figure 3). The return flow was mixed with the raw flow prior to the aeration process. Each of the filters had a volume of $\frac{3}{8}$ cu. yd.; the settling tanks were of adequate capacity to give a minimum detention time of 2 hr. and 1 hr. for the primary and secondary tanks, respectively. The influent to the pilot plant was pumped from the grease pit; this had the double advantage of prior grease removal and smoothing out the range of strength of the waste. Also, on weekends when the industry was not operating there was a source of raw waste. The rates of flow were set each three days, at the end of the 3-day

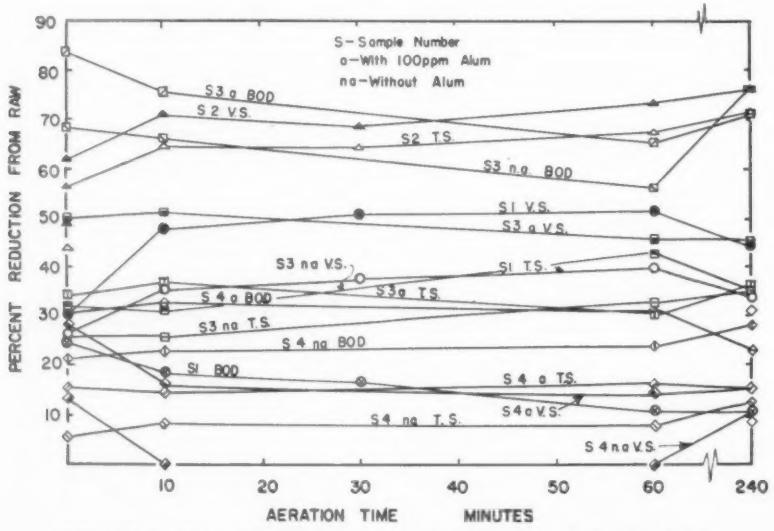

FIGURE 2.—Effect of alum and aeration on solids and B.O.D. reduction in rendering waste.

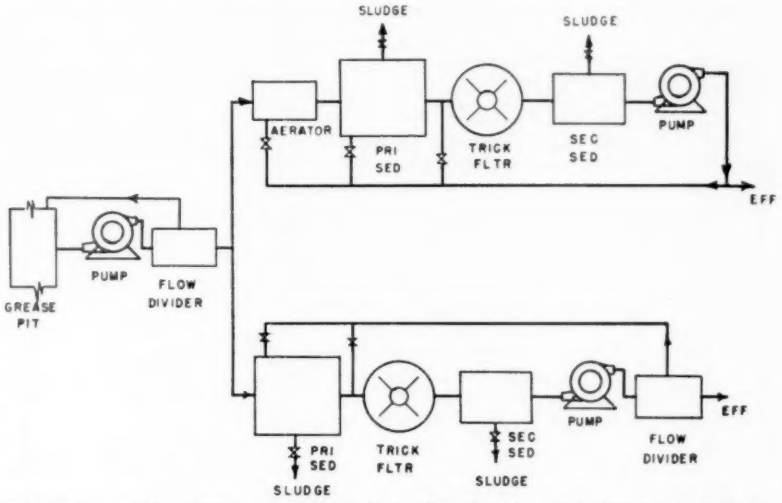

FIGURE 3.—Flow diagram of trickling filter pilot plant for rendering waste treatment.

period, 8-hr. composite samples were taken for analysis. Figures 4 and 5 give the results of the investigation. The B.O.D. values of the raw and effluent samples combined with flow rates and filter volumes were converted to values in pounds of B.O.D. per cubic yard per day applied and removed.

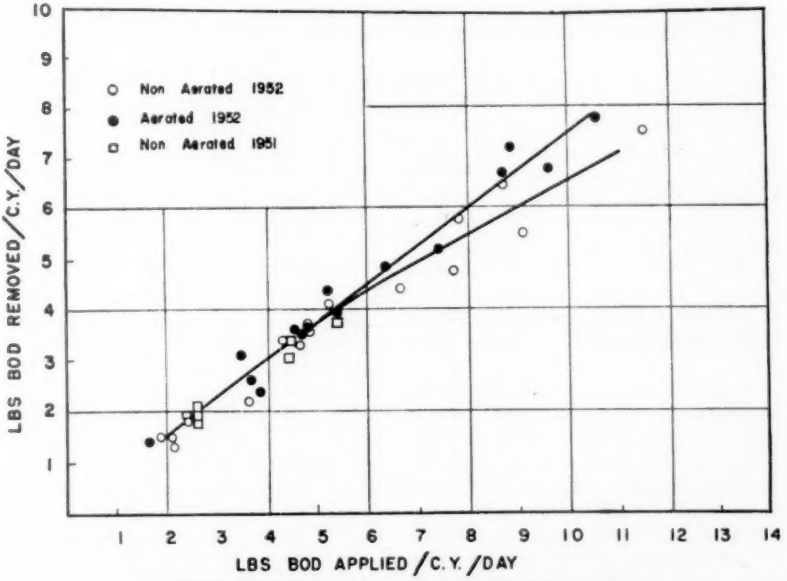

FIGURE 4.—Trickling filter pilot plant B.O.D. results.

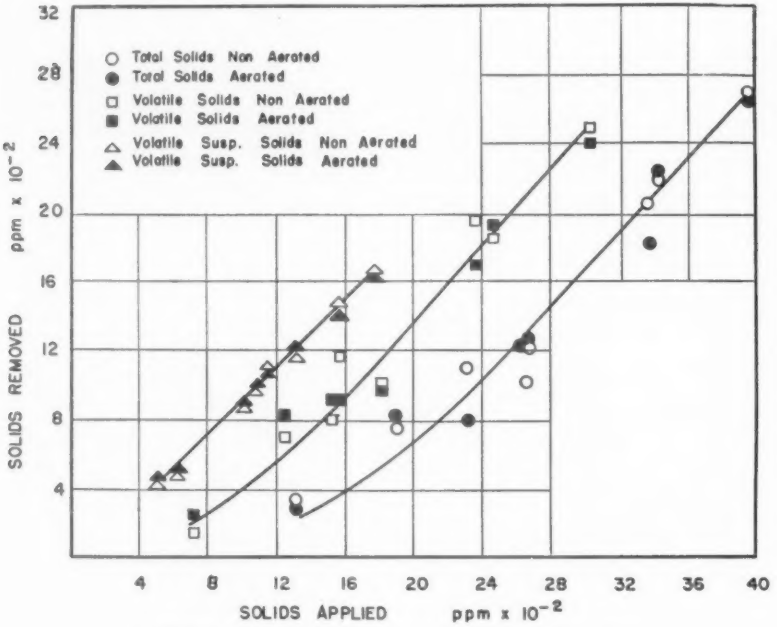

FIGURE 5.—Solids removals in trickling filter pilot plant.

Figure 4 shows that for the non-aerated treatment above 5 lb. per cu. yd. per day applied, the efficiency dropped off slightly, but at loadings of 10 lb. the removal was still 65 per cent. The plant with aeration maintained an almost constant efficiency even with the higher loadings; at the 10-lb. loading the efficiency was about 74 per cent. The recirculation ratio varied from 1:1 to 23:1 with most values from 2:1 to 6:1. The writer was unable to find any significant increase in efficiencies with recirculation ratios greater than 2:1.

In case 75 per cent efficiencies are inadequate, or where a more assured pathogen removal is desired, chlorination of the plant effluent may be used. Portions of the final effluent were treated with a fixed amount of chlorine. When 50 p.p.m. were used the color of the effluent was greatly reduced from gray-black to light yellow and B.O.D. reductions were from 0 to 4 p.p.m. for each p.p.m. of chlorine. When 100 p.p.m. of chlorine were used the ratio of p.p.m. of B.O.D. reduced to p.p.m. of chlorine was similar. It is not apparent that aeration had any effect on solids removal, as shown in Figure 5. At no time was there any nitrite or nitrate nitrogen present.

Anaerobic Fermentation

Anaerobic fermentation has been used successfully in the treatment of strong organic wastes. Since the cost of this type of treatment may be lower and operation simpler than the trickling filter plant, investigations were made on a laboratory scale. The methods employed were the same in both experiments; that is, to each of several bottles of various capacities 1 l. of treated waste was withdrawn and 1 l. of raw waste was added daily. Samples of each were taken for B.O.D. analysis.

The bottles were kept in a water bath at 32° C. In experiment I (see Table I) four bottles having capacities of 1.5, 2, 3, and 5 l. were used, giving average detention periods of 1.5, 2, 3, and 5 days to the waste. Before withdrawing and after adding, the contents were thoroughly mixed by violent shaking for 2 min. Each bottle contained some of the waste from each of the previous additions, so to determine the value of B.O.D. applied to compare with the B.O.D. of the treated waste, a set of coefficients for each of the detention periods involved was computed and the proper coefficient used with the value of the raw B.O.D. of the prior additions. Well-stirred portions of the treated waste were taken for B.O.D. analysis. Only from the 1.5-day bottle were portions of the withdrawn liter taken for B.O.D. analysis after a 1-hr. settling period. From Table I it is seen that detention did not reduce the B.O.D. values very much; in fact, the B.O.D. of the treated sample was oftentimes higher than the B.O.D. applied. However, considerable reduction was noted when the sample was settled.

The experiment was then repeated using 1.5- and 3-day detention times. Not included in the values of Table II are the B.O.D.'s of the unsettled treated samples; the values shown in Table II are for the settled samples only. To show comparison with Figure 4, the values were computed to pounds of B.O.D. per cubic yard per day applied and removed and are plotted on Figures 6 and 7. Letting Y = lb. B.O.D. removed per cubic yard per day and X = lb. B.O.D. applied per cubic yard per day, the equation for the 1.5-day detention is $Y = -0.70 + 0.56X$, and for the 3-day detention is $Y = -0.44 + 0.29X$. The negative intercept is, of course, incorrect, but the straightline portion of the curve includes that value. Since the loadings and removals are computed on a per day value, the absolute values of the intercept and slope are about one-half for the 3-day as for the 1.5-day. The B.O.D. reductions were just slightly better for the 3-day detention than for the 1.5-day detention. The values of the pH dropped during treatment from 0 to 1.5 pH units, but there was no correlation of

TABLE I.—Anaerobic Fermentation, Experiment I

Day	B.O.D. Raw (p.p.m.)	1.5-Day Detention			2.0-Day Detention		3.0-Day Detention		5.0-Day Detention	
		B.O.D. Applied (p.p.m.)	B.O.D. Treated (p.p.m.)	B.O.D. Treated Settled (p.p.m.)	B.O.D. Applied (p.p.m.)	B.O.D. Treated (p.p.m.)	B.O.D. Applied (p.p.m.)	B.O.D. Treated (p.p.m.)	B.O.D. Applied (p.p.m.)	B.O.D. Treated (p.p.m.)
0	4,930	—	—	—	—	—	—	—	—	—
1	3,560	—	—	—	4,930	2,930	—	—	—	—
2	1,480	4,020	1,600	—	4,245	1,900	4,930	1,200	—	—
3	1,670	2,310	1,280	—	2,850	1,290	3,770	1,780	—	—
4	1,270	1,880	1,380	—	2,260	1,240	3,090	1,260	4,930	1,310
5	8,380	1,480	1,800	500	1,770	1,800	2,470	1,700	4,200	2,150
6	3,000	5,910	5,840	1,270	5,070	5,750	4,450	2,000	5,030	1,120
7	1,140	4,030	4,420	2,000	4,040	4,480	3,970	3,400	4,580	3,770
8	1,000	3,000	2,400	910	2,590	2,760	3,030	2,510	3,930	3,410
9	1,980	1,370	1,560	880	1,800	1,640	2,350	1,000	3,340	1,720
10	2,900	1,920	1,540	540	1,890	2,310	2,090	1,330	3,070	3,000
11	1,280	2,380	2,080	900	2,400	2,390	2,390	1,280	3,040	3,450
12	1,500	1,700	1,510	560	1,840	1,400	2,050	1,500	2,690	2,700
13	3,930	1,560	1,610	540	—	—	—	—	—	—
14	4,000	—	—	—	3,590	3,820	—	—	—	—
15	2,800	3,740	2,260	860	3,170	3,370	3,070	—	—	—
16	2,085	3,110	2,115	845	—	—	—	—	—	—

TABLE II.—Anaerobic Fermentation, Experiment II

Day	B.O.D. Raw (p.p.m.)	1.5-Day Detention				3.0-Day Detention			
		B.O.D. Applied		B.O.D. Treated (p.p.m.)	B.O.D. Removed (lb.)[1]	B.O.D. Applied		B.O.D. Treated (p.p.m.)	B.O.D. Removed (lb.)[1]
		(p.p.m.)	(lb.)[1]			(p.p.m.)	(lb.)[1]		
0	7,280	—	—	—	—	—	—	—	—
1	4,300	7,280	—	—	—	—	—	—	—
2	2,290	5,290	8.92	1,390	4.38	6,290	10.60	1,300	2.80
3	5,000	3,290	5.55	1,230	2.31	4,950	8.34	1,140	2.14
4	4,720	4,940	8.32	3,080	2.09	5,000	8.43	1,670	1.87
5	2,880	4,610	7.76	1,700	3.26	4,900	8.26	1,670	1.81
6	2,210	3,460	5.83	1,340	2.38	4,220	7.11	1,190	1.70
7	1,270	2,630	4.43	1,000	1.83	3,530	5.94	700	1.59
8	1,850	1,720	2.90	1,000	0.81	2,750	4.64	1,690	0.60
9	2,630	1,800	3.03	1,560	0.40	2,450	4.13	1,150	0.73
10	1,320	2,360	3.98	760	2.25	2,500	4.21	1,020	0.83
11	2,720	1,665	2.80	1,000	0.75	2,100	3.54	2,090	—
12	1,430	2,370	3.99	1,210	1.30	2,300	3.88	1,100	0.67
13	1,500	1,740	2.93	940	0.90	2,010	3.39	1,560	0.25
14	1,600	1,580	2.66	540	1.17	1,760	2.97	1,100	0.37
15	860	1,590	2.68	600	1.11	1,600	2.70	300	0.73
16	800	1,100	1.85	280	0.92	1,460	2.46	450	0.57
17	1,800	900	1.52	860	0.05	1,240	2.09	610	0.35
18	1,820	1,500	2.53	1,000	0.56	1,420	2.39	1,200	0.12
19	2,700	1,710	2.88	1,120	0.66	1,550	2.61	620	0.52
20	2,150	2,370	3.99	2,260	0.12	1,930	3.25	1,260	0.38
21	3,400	2,220	3.74	1,420	0.90	2,000	3.37	1,520	0.27
22	440	3,010	5.07	850	2.43	2,470	4.16	950	0.85
23	990	1,300	2.19	980	0.36	1,730	2.92	1,090	0.36
24	2,860	1,090	1.84	1,440	—	1,520	2.56	1,080	0.25
25	3,660	2,270	3.82	380	2.12	1,960	3.30	800	0.65
26	2,030	3,200	5.39	570	2.95	2,530	4.26	630	1.07
27	1,470	2,420	4.08	1,070	1.52	2,360	3.98	1,140	0.68
28	1,760	1,790	3.02	1,220	0.64	2,060	3.47	1,220	0.47
29	2,460	1,770	2.98	1,120	0.73	1,960	3.30	1,270	0.39

[1] Pounds per cubic yard per day.

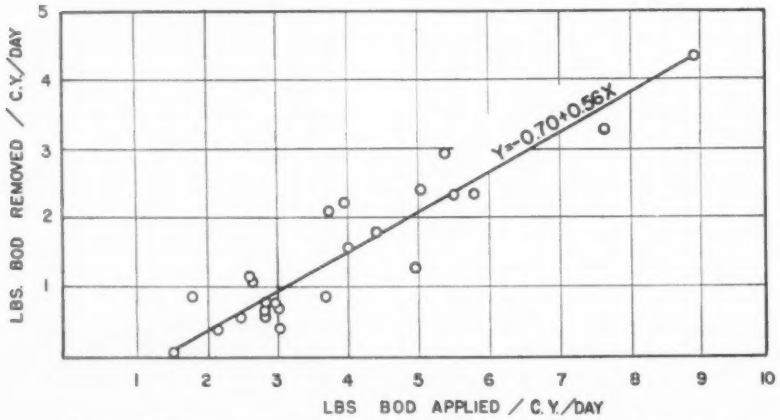

FIGURE 6.—B.O.D. removal by anaerobic fermentation, 1.5-day detention.

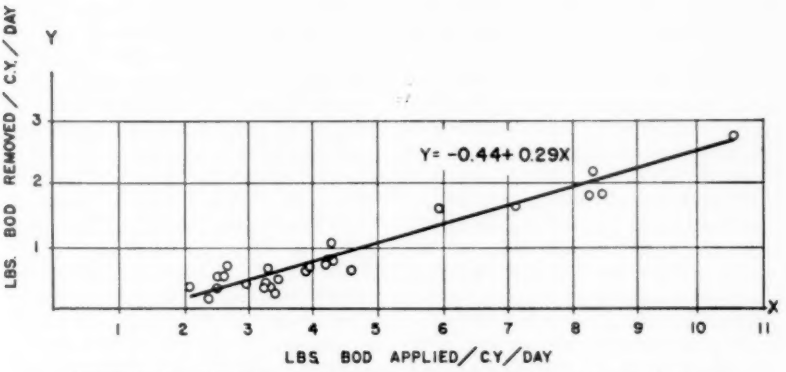

FIGURE 7.—B.O.D. removal by anaerobic fermentation, 3-day detention.

pH change with time or loadings or removals.

Sludge Disposal

Sludge disposal is essential, whatever method of treatment is employed. The sludge, approximately 10 per cent by volume, from the chemical treatment process, dried very well to spadable form in 5 days when applied about 8 in. deep on a drained sand bed. With 100 p.p.m. alum the mixed sludges from the trickling filter plant dried quite well on sand beds, and drained very

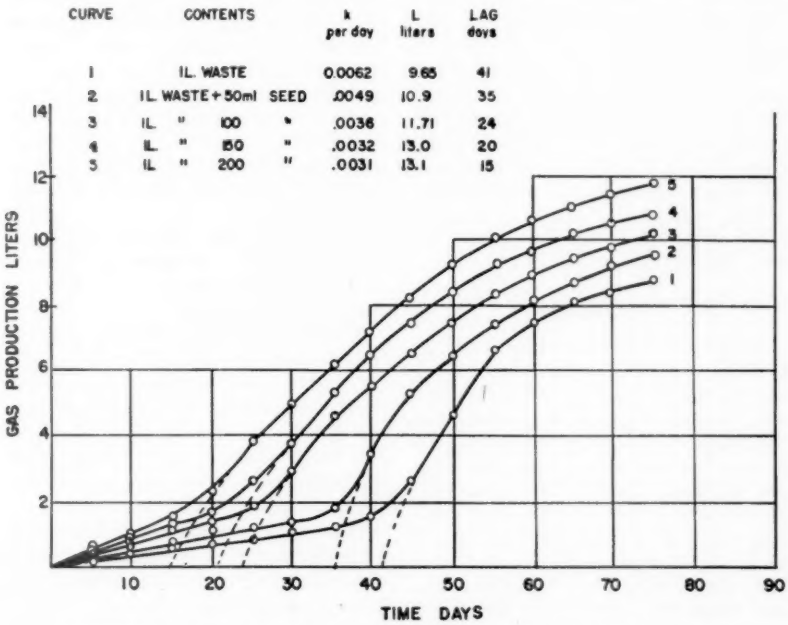
CURVE CONTENTS k per day L liters LAG days
1 1L. WASTE 0.0062 9.65 41
2 1L. WASTE + 50ml SEED .0049 10.9 35
3 1L. " 100 " .0036 11.71 24
4 1L. " 150 " .0032 13.0 20
5 1L. " 200 " .0031 13.1 15
GAS PRODUCTION LITERS
TIME DAYS

FIGURE 8.—Gas production by anaerobic fermentation of rendering waste.

well when a laboratory adaptation of a vacuum filter was used; without alum the sludge dried only fairly well on sand beds, but quite well with the vacuum. The anaerobic treatment sludge drained and dried somewhat better than the trickling filter sludge under the same conditions.

Figure 8 shows the gas production *vs.* time for a batch operation. To 1 l. of waste was added 50, 100, 150, and 200 ml. of well-digested sludge as seed. Daily observations were made of gas volumes and those volumes were converted to standard conditions. The rate of production, reduction of lag time with increase in sludge seed, pounds of gas per pound of volatile matter, and analysis of gas all indicate that digestion is a satisfactory treatment for the sludge. Lag times were estimated by back extrapolation of the curves; the curve was assumed to be unimolecular past the lag period. Values of k (reaction velocity coefficient) and L (ultimate gas production) were computed by the method of linearization. The gas analyzed after 40 days had a methane content of 60 to 69 per cent, the higher value with the sample having the maximum seed. The pounds of gas per pound of volatile matter destroyed varied from 1.3 to 1.47; again, the higher value occurred with the sample having the most seed. This compares with the value 1.25 commonly used for domestic sewage.

Discussion

As previously mentioned, the independent rendering plants, because of the nature of the raw product, often are located beyond the municipal sewer system. In the southeastern part of the United States there are very few of these plants with more than four cookers, thus the wash-water volume will generally be less than 20,000 g.p.d. Most such plants operate on a 5- or 6-day work week. Therefore, the wash-water treatment plant should be as simple and inexpensive as possible. In any case, a grease trap cleaned daily is a necessary pretreatment device; the industry recovers the skimmings and puts them back into the process.

Due to the intermittent flow of wastes, a single-tank batch treatment using chemical coagulation and chlorination would be quite satisfactory. There are several things to consider. The experiments, both on laboratory and plant scale, indicate that for effective B.O.D. removals a minimum chlorine dose is necessary. The value of that minimum dose cannot of course be determined for each batch, so a minimum value should be established. As a result, considerably more chlorine would be used than is necessary; this is an expensive procedure. With the cost of 70 per cent hypochlorite at about \$0.28 per pound, a 350-p.p.m. available chlorine dose for 20,000 gal. would cost about \$21. This does not include the cost of alum, labor, or treatment plant investment. The use of gaseous chlorine would cut the cost, but a chlorinator feeding, say, 80 lb. in a few minutes time would be rather expensive, if at all available, and would require a lot of water. To feed gaseous chlorine without an approved chlorinator is at best a makeshift proposition and there would need be perhaps 10 bottles of chlorine in order not to overdraw each bottle; the laborer would have considerable difficulty handling such an array of chlorine bottles. There might be some negligence in adding the chemicals.

The experimental work using air flocculation with or without alum indicated some advantage over straight settling. Any advantage is as apparent at the end of 10 min. as at the end of 4 hr. The alum, if used, should be added in solution form as late as possible to prevent breaking up of the floc.

The waste is amenable to trickling filter treatment. A recirculation ratio of at least 2:1 should be maintained to improve treatment by dilution and by smoothing out the range of concen-

trations of the raw flow. Aeration of the mixed raw and return flows is of advantage at the higher loading rates, that is, above 5 lb. of B.O.D. per cubic yard per day. The size of units should be determined by considering both volume and strength of the waste. The initial cost of this type of plant is rather high, but the operating cost is much lower than chemical treatment, and operation would be more assured. A difficulty is that the raw flow may be zero on week ends; however, the recirculated flow is still concentrated enough to maintain a good growth on the filter rock. If further treatment is required to reduce the B.O.D. to very low levels and to insure a better reduction of pathogens, chlorine may be applied to the plant effluent.

Anaerobic fermentation is almost as effective in 1.5 days as it is in 3 days. There is essentially no stabilization, only coagulation of the organic matter, so a settling tank should be provided. If the waste is concentrated, considerable B.O.D. removal can be expected; but if the waste is dilute, little value is obtained. The treatment tank should be maintained at a constant temperature. If a high degree of treatment is required, a combination of anaerobic fermentation preceding a trickling filter plant may greatly reduce the initial cost.

The sludge can be handled with standard procedures. With chemical treatment, the sludges from the various processes can be dried on sand beds or vacuum filters. It is unlikely that with such small volumes a vacuum filter would be used. The drying time used in design should be not less than one week for summer temperatures and longer for the winter, depending on local temperatures and experience. In North Carolina, two weeks drying time should be adequate in the winter months. Since the sludge contains materials that can be used in the rendering process, the straight, thickened, or dried sludge could be returned to the cookers. The sludge from the chemical treatment process should perhaps not be returned to the cookers, since the product is used in animal feed, and, even though no definite information is available, aluminum may have adverse effects on animals. Sludge digestion is feasible and design values used for domestic sewage based on volatile solids content would be satisfactory. It is doubtful if sufficient gas would be generated to make recovery economical.

As is the case in many industries, considerable reduction in wastes may be accomplished by minor changes in plant operation. If carts of a noncorrosive metal construction instead of steel drums were used to carry the offal, much better drainage of the contents from the container would be accomplished and wash-water volumes would be greatly reduced. Sweeping of floors and trucks prior to hosing down would also reduce water quantities. A good grease trap skimmed daily would reduce carryover. Other such things might be apparent in each plant.

Conclusions

Waste wash waters from the rendering industry have a high concentration of non-settleable organic solids. Even though there are essentially no carbonaceous-type compounds present, standard methods of treatment are applicable. Inasmuch as the raw material is in a state of partial decomposition, the efficiencies found in treatment of packinghouse wastes are not necessarily to be found with this type of waste.

Further studies could be conducted on a pilot plant scale of the anaerobic fermentation process at both the mesophilic and thermophilic temperature ranges, and also on the use of intermittent sand beds.

Acknowledgments

Acknowledgment is made to E. C. Hubbard, Executive Secretary of the

North Carolina State Stream Sanitation Committee, and to J. M. Jarrett, Chief Engineer, North Carolina State Board of Health, for their encouragement and suggestions. The study reported was made possible by a grant from the North Carolina State Board of Health.

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DISPOSAL OF SPENT SULFATE PICKLING SOLUTIONS

"Disposal of Spent Sulfate Pickling Solutions" is the subject of another manual in the series being published by the Ohio River Valley Water Sanitation Commission to provide authoritative information on treatment methods for industrial wastes. It was prepared under the auspices of the Commission's Steel Industry Action Committee by R. D. Hoak, fellow of the American Iron and Steel Institute, and a subcommittee headed by T. F. Reed, of U. S. Steel Corp.

The 76-page illustrated manual describes neutralization procedures in detail, discusses methods for recovery of various by-products, and includes appendices on analytical methods and determination of basicity factors. Among the by-product recovery methods discussed are those yielding copperas, copperas and sulfuric acid, ferrous sulfate monohydrate and sulfuric acid, iron oxide and sulfuric acid, ferric sulfate and sulfuric acid, iron oxide and ammonium sulfate, construction material, manganese concentrate from lean ore, magnesia from dolomite, electrolytic iron, iron powder, iron oxide pigments, iron sulfates in cement, ferric chloride and sodium sulfate, and ferric phosphate.

Copies of the manual, priced at $2.00, are obtainable from the Ohio River Valley Water Sanitation Commission, 414 Walnut Street, Cincinnati 2, Ohio.

REDUCTION OF MILK WASTE IN DAIRY PLANTS

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Much of the milk wasted in dairy plants originates from little drops of milk from pipelines, equipment, or containers. Because these drops are tiny, their real monetary value, their volume, and their contribution to the waste problem are not readily realized. When the flow of little drops of milk is stopped or they are collected, savings are made and waste is reduced. The elimination of waste, either by stoppage of leaks or recovery of the product, is the easiest and perhaps the most profitable way to deal with the disposal problem.

One source of waste, which can be reduced greatly and economically, and which is common to all plants, is the incomplete recovery of milk from freshly dumped milk cans. This milk residue is high in butterfat, testing 2 to 3 per cent higher than the average test of the milk in the cans. In quantity it varies from 2 to 6 oz. or more per can, depending on the dumping and handling procedure.

Effect of Washer Feeding Method

The majority of the milk received in cans is removed through the dumping process. This is the portion that goes directly into the weigh tank and is used for various dairy products. It represents well over 99 per cent of the total contents of the cans when received. The percentage which goes into the weigh tank may be increased by proper dumping and feeding of the cans into the washer.

Observations were made to ascertain the merits, advantages, and disadvantages of two common practices of feeding the dumped can into the washer using the Western grid dump, which is the fastest and most efficient dumping method.

The correct dumping method with the dump grid consists of rolling the can over the dump block and up-ending it onto the grid, which extends from the washer over the weigh tank strainer. After the can is inverted over the weigh tank it is fed to the washer. The time and manner in which the can is moved forward to the machine makes a significant difference in the amount of milk remaining in the can.

Many operators follow the practice of inverting the can over the grid and immediately moving it forward to the load position of the washer. This method of feeding the cans to the machine is improper, because it produces unnecessary waste without improving operating efficiency.

The proper method is to permit the up-ended can to remain on the grid to drain while the cover is removed from the succeeding can and placed in the cover pocket of the washer. Then the can is moved forward to the load position. This additional drainage time over the weigh tank greatly reduces the volume of milk wasted.

Field Tests

The difference in milk losses between the two methods of feeding the cans was determined by actual field tests. The distribution of the milk from 1,000 10-gal. cans fed improperly and 1,000 10-gal. cans fed properly is shown in Table I. The figures pertaining to the cans fed improperly were obtained by extending the results from dumping

700 10-gal. cans. The tabulated results are, therefore, readily comparable. All cans were handled in the same plant on the same day by the same operator. These observations were made in July, 1951, with a can washer operating at 14 cans per minute. The average temperature of the milk received was 56° F., with an average butterfat content of 3.55 per cent.

The total milk retained in the 1,000 freshly dumped cans, improperly handled, was 406 lb., whereas only 220 lb. remained when proper can handling procedures were followed. This represents a reduction in milk waste of more than 45 per cent by changing the method of dumping and feeding the cans into the washer.

This reduction in waste would save more than 67,000 lb. of high testing milk annually in a plant which received an average of 1,000 cans per day (containing 70,600 lb. of milk) throughout the year. It is evident, therefore, that proper dumping and feeding of the can into the washer is a "must." It is unfortunate, however, that this "must" gets its emphasis from the problem of waste disposal. The economic advantages of proper handling procedures are ample reward for their adoption, especially since they can be applied in any plant without additional equipment or delay in operation.

Means for Further Reduction

Even under poor operating conditions, all but a fraction of 1 per cent of all milk received goes into the weigh tank, and when the cans are properly handled this fraction becomes quite small. This small fraction of 1 per cent of milk adheres to the can surface and usually goes to the sewer through drippings and can washes unless recovery measures are taken.

The recovery should be as complete as possible and in a manner that will preserve the wholesomeness of the milk. The simplest, easiest, and most economical way to accomplish this is to allow ample time for the milk to drain out naturally. This avoids the problems encountered when liquid sprays, wetting agents, steam, or compressed air are used to obtain more rapid and more complete removal of the milk solids. In the plant studied, 1,000 10-gal. cans properly handled retained 220 lb. of milk, from which 158 lb. were subsequently recovered by providing ample drainage time.

The drained milk was collected in individual receptacles at the washer load position and at five additional can drain positions. The time each can remained over the load position was determined by the use of a stop watch, whereas the operating speed of the machine was used to calculate the time for each drain position. As would be expected, the amount of milk recov-

TABLE I.—Effect on Milk Losses of Methods of Feeding Cans to Washer
(1,000 10-Gal. Cans)

Disposition of Milk	Fed Improperly		Fed Properly	
	Milk (lb.)	% of Total	Milk (lb.)	% of Total
Into weigh can	70,100	99.424	70,617	99.690
Recovered by natural drainage	337	0.478	158	0.223
Unrecovered, left in cans	69	0.098	62	0.087
Total contained in cans	70,506	100.000	70,837	100.000
Milk recovered:				
per can	0.337	—	0.158	—
per 100 lb. received	0.478	—	0.233	—

TABLE II.—Milk Collected from 1,000 Properly Handled 10-Gal. Cans

Drain Position	Drip Yield (lb.)		Butterfat (%)	Cum. Drain Time (sec.)	Ann. Savings[1] (lb.)	% of Total	
	Position	Cumulative				Position	Cumulative
Load	80	80	—	2.33	29,200	50.63	50.63
1st drain	34	114	5.8	6.62	12,410	21.52	72.15
2nd drain	19	133	5.7	10.91	6,935	12.03	84.18
3rd drain	10.5	143.5	5.6	15.20	3,832	6.64	90.82
4th drain	8.5	152	5.5	19.49	3,103	5.38	96.20
5th drain	6	158	4.6	23.78	2,190	3.80	100.00

[1] Total = 57,670 lb., of 123,005 lb. lost by improper handling.

ered decreased progressively with prolonged drainage. The relative importance of each drain period can be readily evaluated from Table II.

By allowing the cans to drain for nearly 24 sec., 158 of the 220 lb., or more than 70 per cent of the residual milk, was recovered. This reduction of waste would save more than 57,000 lb. of high testing milk annually in a plant averaging 1,000 such cans per day throughout the year. Since more than 29,000 of the 57,000 lb. were collected at the load position, means should be provided wherever possible to save this milk by diverting it into the weigh tank or the receiving tank.

The time allowed for drainage recovered 0.223 per cent of all milk received when the cans were handled properly, thus reducing the milk waste to less than 0.1 per cent of the total can contents. When cans were properly handled the same drainage time recovered nearly 0.5 per cent of all milk received. Prolonged drainage was accomplished by collecting the milk from five drain positions, which were obtainable due to a sanitary extension integrated with the can washer. The milk contact parts of the extension are made of stainless steel and are readily accessible for cleaning so the quality of the milk is not affected.

The monetary value of the milk saved and the reduction in waste would seem sufficient to warrant whatever changes may be necessary in existing equipment to provide adequate drainage time.

Cumulative Effect of Progressive Drainage

The volume of milk drained from each can gradually decreased from one drain position to the next, or with the passing of time, until eventually practically all drainable milk had been recovered. More than 90 per cent of all milk was recovered in the first 15 sec. of drainage, whereas 20 sec. brought the total to 96 per cent.

The time provided for drainage is of more importance than the number of drain positions. The can washer in which the tests were made had a speed of 14 cans per minute. Slower machines obviously would not need as much drain space to get results comparable to those reported with the 14-c.p.m. unit. An 8-c.p.m. washer for example, with the load and three drain positions, would provide more drain time than was obtained with the load and five drain positions in the 14-c.p.m. unit.

Impracticability of Additional Drainage

From a practical viewpoint the question arises as to how much drain time should be provided. To find the answer, a test was made to determine the value of additional drainage and also to find out how much milk remained in the cans after they had been drained for 23.8 sec. The plant in which this test was made received only 8-gal. cans. In the test 25 8-gal. cans, dumped in a

TABLE III.—Total Milk Solids Collected from 25 8-Gal. Freshly Dumped Cans

Position	Drain Time (sec.)	Total Sol. Collected		Butterfat Collected	
		(oz.)	(%)	(oz.)	(%)
Load and drain	23.8	8.2515	71.651	3.1139	70.51
Second 5 drains	21.5	.5412	4.584	.2080	4.71
Wash and rinse water	—	2.8032	23.765	1.0944	24.78
Total	—	11.5959	100.000	4.4163	100.00

manner which minimized waste, delivered a total of 1,564 lb. of milk into the weigh can.

The cans were then allowed to drain for 23.8 sec. They were subsequently drained over another receptacle for 21.5 sec., which was equivalent to five additional drain positions on a 14-c.p.m. washer. Milk collected was tested for total solids and butterfat. The drained cans were thoroughly washed by hand with clear warm water and then rinsed with clear warm water. All wash and rinse waters were collected, weighed, and tested for total solids and butterfat. The results are given in Table III. Although the detailed study was limited to 25 cans, the results were verified by collecting milk from 1,000 8-gal. cans at the load and five drain positions. The rate of recovery was 2.44 oz. per can from the 25-can lot and 2.43 oz. from the 1,000-can lot. The recovery per 100 lb. of milk received, however, was 3.90 oz. in each case.

The additional five drain positions providing 21.5 sec. more drain time accounted for only 4.584 per cent of total solids recovered, whereas the 23.8 sec. of initial drainage recovered 95.416 per cent of all drainable milk. To recover the additional 4.584 per cent of total solids would require a much longer can washer and a longer receiving room. The savings do not appear to justify the added cost that would be involved for most plants.

Unrecovered Milk Adds to Waste Problem

Proper can handling and the recovery of milk through natural drainage will reduce milk waste significantly. The waste problem still exists, however, because of the non-drainable milk adhering to the can, as well as that which is drainable but apparently cannot be recovered economically. The adoption of the recommended practical recovery methods will make it possible to keep the volume of such waste milk well below 0.1 per cent of the total intake.

Effect of Water

In large-volume plants, or in localities where further reduction of milk waste is necessary, other means may be utilized to prevent a large part of the non-drainable milk from entering the sewer. The use of atomized liquid sprays, wetting agents, steam, compressed air, and the recirculation of liquids have been considered as possible means of accelerating and bringing about more complete removal of milk from the cans. The use of liquid sprays provides more complete removal of the residual milk than can be obtained through natural draining, but they are somewhat objectionable because the utilization of the recovered diluted milk is limited.

A study was made to determine the possibility of more complete removal of the milk from the can by spraying a small volume of water into each can. The aim was to recover as much milk as possible without dilution so that the undiluted milk could be run directly into the milk supply. A fine water spray was, therefore, applied to 500 individual 10-gal. cans in drain position No. 4 and to another 500 cans in posi-

tion No. 2. By applying the spray in position No. 4 much more milk was recovered by natural drainage without dilution than could be obtained by adding the spray earlier (in position No. 2). All liquid drained from the cans was collected at each position, weighed, and tested for butterfat and total solids.

An attempt was made to inject approximately 3 oz. of water into each can. However, when the total volume of liquid had been collected, tested, and converted to milk containing 12.5 per cent total solids, it was found that the approximate average amount of water injected in the fourth position was 3.14 oz. per can, whereas only 1.66 oz. had been applied to the cans where the water was used in position No. 2.

It was expected that by applying water in position No. 2 to provide more time for drainage, more total milk solids could be recovered than by applying the same amount of water with less drainage time. Total solids recovered from each set of 500 10-gal. cans were approximately the same. Specifically, 3.14 oz. of water applied to each of 500 cans delivered 12.407 lb. of total solids, and 1.66 oz. of water applied to each of 500 cans delivered 12.527 lb. of total solids.

The use of nearly twice the volume of water with 9 sec. of drainage delivered approximately the same total solids as was obtained with a small volume of water and 18 sec. of drainage after applying the water.

Natural drainage supplemented with 1.66 oz. of water per can, after which 17.96 sec. of drainage occurred, removed 86.3 per cent of the total solids from cans, whereas natural drainage supplemented with 3.14 oz. of water per can, after which 8.58 sec. of drainage occurred, removed 85.98 per cent of the total solids. Tests made at the same plant as reported recovered 71.65 per cent of the total solids through natural drainage. In plants where it is necessary to keep stream pollution at the very minimum, the use of a larger volume of water with less drainage time is recommended, because more milk can be recovered without dilution. Both methods, however, reduced the loss of milk to less than 0.05 per cent of the total milk received during the test period.

Utilization of Recovered Milk

The waste disposal problem cannot be reduced by recovering the drained milk unless this milk is fully utilized. Unused milk is still a part of the waste problem. By collecting the milk in a sanitary manner it is of the same quality as if it had drained into the weigh tank by permitting the can to remain in the dump position for a longer period. The fact that the can is in motion while draining does not reduce the wholesomeness of the milk.

If this collected milk went directly into either the weigh tank or the receiving tank, or where is could be utilized with the current milk receipts, the waste disposal problem would be reduced materially.

Summary

1. The results contained in this report are what might be expected in any plant during the summer months and under like conditions. Further study of this problem, however, will be necessary to determine the effect of winter weather on the recovery of milk from the cans.

2. Incomplete recovery of milk from freshly dumped milk cans is a common source of waste. The volume of milk remaining in the dumped can is affected by the manner in which the cans are dumped and fed into the can washer. By providing for a slight pause over the weigh tank, milk losses are reduced substantially. The adoption of this practice is highly recommended.

3. Nearly 50 per cent of the drainable milk remaining in properly handled cans may be recovered at the load position, while more than 95 per cent can be recovered by providing 21.5 sec.

additional drainage. Therefore, means should be provided wherever possible to divert this milk into either the weigh tank or the receiving tank for immediate use.

4. If the can washer is equipped with a sanitary extension to provide at least 21.5 sec. of drainage beyond the load position, much milk can be saved. The milk zone of the extension should be made of stainless steel and of sanitary design, so that all parts can be easily cleaned.

5. Prolonged drainage, at least in warm weather, does not appear to be worthwhile, since 21.5 sec. beyond the load position recovered approximately 95 per cent of all drainable milk, whereas doubling the drainage time saved less than 5 per cent additional solids.

6. A small volume of water sprayed into each freshly dumped milk can may be utilized to bring about more complete recovery of milk solids.

7. The recovered milk should be fully utilized, otherwise it is still a part of the waste problem. If it is collected in a sanitary manner, it will be of the same quality as if it had drained directly into the weigh tank. The fact that the can is in motion while draining does not reduce the wholesomeness of the drained milk.

Acknowledgments

Appreciation is due the splendid services rendered by the Bowman Dairy Co., its officers, factory, and laboratory personnel, and particularly William Mair, who gave his time and services unstintingly in helping with this project. Thanks are also due William Dean, chief engineer, Bowman Dairy Company; E. H. Parfitt of the Evaporated Milk Assn.; and W. J. Corbett of the Dean Milk Company, Rockford, Ill., for their counsel and assistance in planning this study and evaluating the results.

The author's interest in this subject has been stimulated, also, by being a member of the Waste Disposal Task Committee of the Dairy Industry Committee. This study, therefore, may be considered as a contribution by the Task Committee toward achieving its major aim of waste prevention.

DETERMINATION OF CYANATES

In the paper on "Colorimetric Determination of Cyanide, Cyanate, and Thiocyanate in Sewage and Plating Wastes," by Kruse and Mellon (THIS JOURNAL, **24**, 10, 1254; Oct., 1952), the statement was made that no method for cyanate determination more sensitive than 50 p.p.m. could be found in the literature. A reader points out, however, that since the manuscript was processed a method has been published by Zabban and Dodge (*Plating*, **39**, 381; 1952) for cyanate determination good to at least 1 p.p.m.

A RATIONAL APPROACH TO INDUSTRIAL WASTE DISPOSAL PROBLEMS*

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The Water Pollution Control Act of 1948, Public Law 845, has done much to focus attention on the contamination of public waters by industrial wastes. Quotations from government publications and from speeches by government representatives typically emphasize the critical situation that faces the nation due to the inroads of pollution upon the supply of clean water, and frequently stress the magnitude and complexity of the industrial waste problem.

Industry is not solely responsible for this situation; domestic wastes also burden the nation's waters. Thus, the responsibility of abatement must be shared by industries and municipalities alike, and their joint action must be stimulated by a fair administration of the problem based on an intelligent and competent appraisal of our present and future needs.

Admitting the difficulty of carrying out a comprehensive waste disposal survey of the United States, it nevertheless is of interest to note that reports of government surveys seldom compare the relative magnitude of industrial waste contamination and contamination caused by sanitary sewage. The wastes from our industries are varied and complex, and comparison with sanitary wastes is difficult. Basically, public health is the prime consideration. Forgetting for the moment such "yardsticks" as oxygen demand, bacterial count, or some similar property, but keeping in mind the general concept of public health, it is the author's opinion that untreated sanitary wastes constitute as great a problem if not a greater one than do industrial wastes.

The purposes of this paper are: (a) to point up these views by estimating the pollutional load contributed by the petroleum refining industry in the United States, and by analyzing this load in comparison with data published by the United States Public Health Service on total pollution; (b) to outline a concept for establishing a fair administration of the national pollution problem; and (c) to discuss the possible future trends in petroleum refinery waste treatment.

Petroleum Refining Wastes as an Example of Pollution

There are few, if any, published data that quantitatively assess contamination of the public waters by industrial wastes. The reports on the various river basins issued by the U. S. Public Health Service are the best attempts at doing so, but perusal of these reports reveals many gaps in the data. In view of this, the author has chosen to look at the oil refining industry by extrapolating certain unpublished data for a limited amount of refining capacity to the present level of crude refining in the United States. It is important to emphasize that the resulting data are not representative of total industry, but illustrate the pollution load attributable to a single

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major industry, which also uses large volumes of water.

Like most industries, oil refineries use more water than any other raw material. Virtually every operation from primary distillation through final treating requires large volumes of process and cooling water. This demand is estimated by the National Association of Manufacturers (1) at 770 gal. per barrel of crude oil. Based on a national crude run of 7,000,000 bbl. per day (2), the water used by all refineries is about 5,400 m.g.d. This volume is second only to that required by the steel industry.

According to estimates by the President's Water Resources Commission (3), the total water consumption in the United States is 100,000 to 150,000 m.g.d. Table I shows the amounts withdrawn for industrial and domestic uses; 90,000 to 100,000 m.g.d. for irrigation are not shown. Comparing these data with oil refinery usage (5,400 m.g.d.), it is readily apparent that the refinery consumption is about 20 per cent of industrial and slightly less than 50 per cent of municipal needs. Thus the oil industry is indeed a major factor as far as water usage is concerned.

The geographic location of the 341 operating refineries in the United States is such that these plants are contained in 14 of the 15 watershed basins designated by the U. S. Public Health Service (4). Like many other major industries, oil refining activities are concentrated in five heavily populated basins; namely, the North Atlantic, Upper Mississippi, Southwest-Lower Mississippi, Western Gulf, and California.

TABLE I.—Water Withdrawals in the United States (Billions of Gallons per Day)

Use	Ground Water	Streams and Lakes	Total
Industrial	5	20	25
Municipal	3	9	12
Rural[1]	2	1	3
Total	10	30	40

[1] Excluding irrigation.

The extrapolation of refinery waste data on the basis of crude run necessarily assumes that crude quality, process methods, and waste treatments are similar throughout the industry. This is no doubt an assumption that can be challenged, but, based upon data which the author has seen, this assumption is not as invalid as might be thought at first glance.

The average refinery in the United States processes 20,500 bbl. of crude per day. Table II shows the estimated quantity and quality of the effluent water from this average refinery. Of the 16 m.g. discharged daily, approximately 10 m.g. are used for cooling and are essentially free of contamination.

TABLE II.—Data for Typical Oil Refinery

Crude run (bbl./day)	20,500
Water usage (m.g.d.)	16
Effl. water quality:	
Oil content (bbl./day)	16
Phenolics (lb./day)	380
B.O.D., pop. equiv.	31,500

The remaining 6 m.g. are process water that has contacted oil in various stripping, washing, and treating operations. Most of the total effluent is subjected to some treatment before discharge, probably in a gravity-type oil-water separator.

Oil and phenolics are the principal contaminants in refinery waste waters. The average refinery discharges 16 bbl. per day of oil (less than 0.1 per cent of the crude run) and 380 lb. per day of phenolics (about 0.02 lb. per barrel of crude run). Other contaminants and properties less frequently reported are: suspended matter, dissolved solids, ammonia nitrogen, turbidity, and odor. Although several of these factors are interrelated, each has a definite bearing on the health of the receiving waters. Approximate values for the amount of each added to the water upon passage through the average refinery are as follows: suspended mat-

ter, 25 p.p.m.; dissolved solids, 250 p.p.m.; ammonia nitrogen, 2 p.p.m.; turbidity, 90 p.p.m.; threshold odor number, 16,000 at 25° C.

The B.O.D. provides a convenient means of comparing industrial wastes with sewage, and for such comparison it is usually converted to population equivalent. It is perhaps of interest to note that the population equivalent of 31,500 for the average refinery effluent is approximately 1.5 times the crude run. The B.O.D. of refinery wastes (39 p.p.m.) is relatively low, but because of the large quantity of water used, the population equivalent is high.

The estimated national refinery pollution load is shown in Table III. As stated previously, these data are based on a daily crude run of 7,000,000 bbl.

TABLE III.—Data for Total Oil Refining Industry

Crude run (bbl./day)	7,000,000
Water usage (m.g.d.)	5,400
Effl. water quality:	
Oil content (bbl./day)	5,400
Phenolics (lb./day)	130,000
B.O.D., pop. equiv.	10,500,000

According to the U. S. Public Health Service (4), the total industrial plus domestic pollution load is in excess of the raw untreated sewage from a population of 150,000,000. According to the extrapolated data, oil refineries contribute 7 per cent of this load. Assuming, as does the U. S. Public Health Service (4), that untreated domestic sewage comprises slightly less than one-half the 150,000,000 population load, perhaps about 70,000,000, it is apparent that this sanitary pollution load is approximately 7 times that of the total refinery load.

These data indicate that even though the oil industry is a major water user its wastes do not pose anywhere near as great a problem as one might suppose. More important than B.O.D. is the fact that untreated sanitary sewage is highly contaminated with bacteria, a demonstrated menace to public health. Refinery wastes, on the other hand, show a negligible coliform bacteria count because most refineries segregate their process and sanitary sewage, and directly or indirectly treat the latter separately.

The inference should not be drawn from this discussion that refineries or total industry should be relieved of responsibility in abatement programs. The evils of unabated pollution are well known. The author's contacts in industry have revealed a constructive attitude toward this problem. Where practical engineering solutions are available for problems that need solving, industry will surely take the lead in installing the necessary treatment facilities. The current problem is not one of proving that there is need for industrial pollution abatement, but rather one of establishing the optimum degree of treatment from the standpoint of the nation as a whole.

Methods for Controlling Water Pollution

Public Law 845 (5) has stimulated considerable attention to the pollution problem, and the United States Public Health Service has promoted a model state law which proposes, among other things, that state waters be classified and standards be established for each class of water. Under this law state agencies would act as "judge, jury, and prosecutor" in all matters of water pollution.

According to Feller and Newman (6), about one-half of the states have either classified their streams or established standards for water purity, and are therefore in accord with the recommended model law. It is quite likely that additional states will consider adoption of legislation similar to the model law.

As regards interstate waters, Public Law 845 expressly delegates power to the states to "negotiate and enter into agreements or compacts," the agreements being subject, of course, to ap-

proval by the Congress. An example of such action is that existing (7) under the Interstate Commission on the Potomac River Basin, involving West Virginia, Virginia, Pennsylvania, Maryland, and the District of Columbia. Many other state and interstate groups report similar programs, and the trend towards such joint action will probably continue to grow, since it is more logical to consider the problem of pollution of a stream and all the tributaries in its entirety, rather than in its isolated parts.

A fundamental difficulty in all such legislation is the problem of defining what constitutes pollution. One method which has been developed is that of classifying the streams according to the use made of the waters. The Interstate Commission on the Potomac River Basin has adopted basic water quality criteria (8). The Commission reports that these criteria were drawn up after months of discussions and negotiations between municipal and industrial groups. The four classifications, A through D, have been established according to water usage, and the minimum quality requirements for each class are based on coliform count, color, turbidity, pH, B.O.D., and dissolved oxygen. These basic water quality criteria are used for measuring the condition of the streams and purity of water within the Basin, and will enable the proper state agencies to administer abatement programs in their respective areas. This appears to be a logical method, and other state and interstate groups are using a similar approach.

Another and quite different method of handling the problem is based on the "reasonable use" doctrine. An illustration of such an approach is the Water Resources Act of the State of Michigan. This Act in broad terms gives the state agencies power to "prohibit the discharge of any wastes which are injurious to public health, fish life, or established occupation." However, while the Act also gives authority to the agencies to establish pollution standards for the state waters, the author understands that no such standards are in existence or are being considered. The proponents of this method of administering anti-pollution legislation contend that each water pollution situation must be considered on its individual merits, rather than by reference to arbitrary standards, in order to arrive at an equitable solution.

Still other abatement groups advocate the control of stream health through bio-assays (9). This certainly is a fundamental tool for controlling or measuring pollution, and recognizes the net result of the pollution load and the recovery ability of the receiving water.

It seems that any method of control involving standards might well run afoul of serious administrative problems, as illustrated by the following hypothetical situation. Certain classified waters are being maintained just within the prescribed standards when a new industrial operation is proposed for the area. The wastes from the new industry constitute an appreciable waste disposal load. Does the new industry have to face the probably heavy cost of completely treating its wastes before discharge? Or should the established waste producers be forced to increase the treatment of their wastes to make room for the newcomer? Perhaps the prospective newcomer should be advised to locate in some other community or state? Sound answers to these questions would seem to be difficult to arrive at.

What, then, is a rational approach? Admittedly, the nationwide problem is too complex to be amenable to a single treatment, and it would seem that the problem should be considered separately for each major watershed. Suitable watersheds have been designated by the U. S. Public Health Service (4). In assessing the pollution abatement needed for the various water-

sheds, consideration should be given simultaneously to the following items:

1. Reasonable uses for which the receiving waters should be suitable.
2. Health of the receiving water and its capacity to assimilate wastes.
3. Present and future pollution load.

The impression is gained from the technical literature on the subject that, to date, great stress has been laid on determining the pollution loads (item 3), but little attention has been given to the first two items. Full consideration of these criteria is a complex procedure. To start with, the parties who might support specific uses (and resultant desired qualities) for a given body of receiving water would be large in number and divergent in interests. Similarly, the same would be true of the parties who might wish to dispose of wastes to the stream and it is apparent that a veritable Solomon is needed to arrive at fair decisions, especially in regard to item 1. It would seem that the Federal Government should work at this job, guiding the necessary basic studies, helping establish fair schemes for pollution abatement, and otherwise acting in a high-level advisory capacity.

A prime feature of a pollution abatement program for any watershed should be flexibility and adaptability to such changing conditions as industrial growth. With this sound framework, the assignment of municipal and industrial abatement responsibilities could be made equitably. The Government's function in the program would be one of advisory service; the watershed control agencies would be responsible for making and enforcing specific rules.

Abatement Responsibility and Possible Future Trends

The responsibility for future abatement must be assumed by the industries and municipalities contaminating the waterways. Whatever actions they take should result from a full understanding of the problem and a conviction that the abatement programs are fair and as near optimum as possible. This is of paramount importance.

To date, federal, state, and local surveys, which are in many instances incomplete, have not yet provided a clear picture of the problem. Nevertheless, federal reports frequently set forth the number of new industrial and municipal plants required for abatement. There have been local claims against industry recommending the construction of plants to eliminate specific wastes. One gathers the impression from such instances that the only goal being considered is that of pristine purity for all waste effluents.

To illustrate, one domestic water treating plant uses excessive activated carbon to eliminate hydrocarbon odors and contends that the effluents from several refineries considered responsible for the presence of the hydrocarbons should be so treated that the city would not suffer any of this disability. It has been calculated that, for a two-year period, the excess carbon costs about $31,000 per year. A rough estimate of the cost of treating the effluents from the several refineries to effect marked improvement in odor characteristics amounts to about $20,000,000 of capital investment and an operating cost of $500,000 per year. It is doubtful if these expenditures would be preferable to the $31,000 per year, from the standpoint of the best interests of this community or of the nation. However, there is no doubt an optimum point between these extremes involving some additional treatment of the effluents from the several refineries, but this point must be very close to the present level of treatment.

A second, less direct example may be outlined as follows: Some news space has been given the problem of establishing standards for water suitable for industrial uses. It has been the author's impression that sheer wa-

ter availability is a "must" to industry, but water quality is a matter for each individual plant to solve, along with such problems as fuel supplies or raw material availability. It would be a step in retreat from the free enterprise system if industry were to subscribe to the idea that the state is obligated to provide industrial water supplies meeting certain specifications. As a by-product of such a philosophy one can imagine the bureaucracy that would be established to insure the delivery of floods of specification water.

The situations just discussed have arisen because of a lack of thorough knowledge of the problems and failure to put the many pertinent factors in proper perspective. An approach to the problems in the various watersheds with due regard to the three criteria previously outlined should prevent such situations and enhance the cooperation of governmental and industrial groups; such cooperation is needed in solving this natural problem.

Future Developments

Whether or not one is willing to accept the U. S. Public Health Service estimates for new waste treating facilities, the future municipal and industrial treating needs will be large, and, directly or indirectly, the individual citizen will foot the bill. No attempt has been made here to make an independent estimate of what this bill will amount to for industry. However, a brief mention of possible future developments in the oil refining industry from a quality standpoint may be of interest.

The petroleum industry has an excellent record for taking a reasonable and constructive attitude toward waste control. The brochure of the National Association of Manufacturers (1) states that the petroleum refining industry leads all industry in the treatment of wastes. It can be estimated that these facilities have cost about $150,000,000. In addition, most refineries employ technical staffs that devote full time to existing waste disposal problems, and to research and development on new and improved methods of treatment. Progress in these activities points to the following future developments:

1. More complete removal of oil from effluents.
2. Elimination of strong waste chemicals from effluents.
3. Reduction in compounds that produce taste and odor.

These developments probably will be accomplished by greater use of closed cooling-water systems and by secondary treating methods. Table IV illustrates the reduction in effluent contaminants expected from chemical flocculation and biological treatments. It is to be noted that both of these treatments effect a significant reduction of oil and odor. The biological process removes both dissolved and suspended contaminants, as the data in the third column for suspended matter and phenolics illustrate. The chemical flocculation process removes principally suspended matter. These treatments, although effective, are expensive, entailing an estimated capital investment of $150,000 per million gallons of water capacity. This would amount to $2,400,000 for the average refinery. Continuing research may discover ways of lowering this cost.

TABLE IV.—Reduction in Refinery Effluent Contaminants by Secondary Treatment

Contaminants and Properties	Reduction (%)	
	Chem. Floc.	Biol. Treat.
Odor number	95	90
Turbidity	93	85
Oil	90	75
Susp. matter	65	45
B.O.D.	50	85
Phenolics	0	90

It is apparent that the oil refining

industry is alert to this national problem and stands ready to take such further action as might be necessary and reasonable under a fairly administered program. No doubt the same is true of all United States industry. Certainly, a fair and objective assignment of responsibilities must be made if the full potential of the country is to be realized.

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In editing the paper by G. E. Hauer on "Successful Treatment of Dairy Waste by Aeration" (THIS JOURNAL, 24, 10, 1271; Oct., 1952), certain acknowledgments were omitted. It should have been pointed out that the current operational data on the Huntley and Chemung, Ill., plants of the Dean Milk Company were used by permission of Baxter and Woodman, consulting engineers, Crystal Lake, Ill., who designed the plants and supervise their operation for the owner.

COLOR IN INDUSTRIAL WASTES *

III. Color of Suspended Solids, and Applications for Waste Color Characteristics

By Willem Rudolfs and William D. Hanlon

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Recently, two methods (1)(2) have been presented for determining the color characteristics of industrial waste solutions. Since the appearance of a stream water is also affected by the type and concentration of suspended material, studies were made to establish a tentative method for measuring the color of industrial wastes in terms of suspended solids, or turbidity.

The color of an industrial waste, from the standpoint of suspended solids, is considered as the luminance of the light transmitted by a colorless solution having the same quantity of suspended matter as the unclarified waste, and the hue of the light reflected from the suspended solids. The hue of the light reflected from the suspended solids may be determined by the utilization of reflectance determinations, and the color of reflected light may be determined by the basic method described for waste solutions (1)(2). However, until a suitable method has been established for determining the reflectance of suspended solids in waste solutions, the color measurement of suspended solids will be limited to a visual description of the hue of the light reflected from the suspended matter, and the luminance of the light transmitted by the suspended solids. The lumninance value is designated by the term "turbidity."

A method was not developed for determining the color characteristics of the reflected light from a waste solution because it is doubtful that reflectance color data would be of as much value. For example, pure water has a transmission luminance of 100 per cent and purity of 0 per cent; hence, water is colorless. On the other hand, white suspended solids in waste solutions might have a reflectance luminance of 100 per cent and purity of 0 per cent and still be highly noticeable in water. It follows that the color of suspended solids as determined by reflectance measurement might be of limited value.

Apparatus

The apparatus used was the same as that specified in the spectrophotometric (1) or filterphotometric (2) methods for determining waste solution color characteristics, and consisted of a spectrophotometer or filter photometer, glassware, filter crucibles, filter aid, and a vacuum system.

Procedure

Preparation of the Sample

Two 50-ml. waste samples were prepared for luminance determinations by bringing both samples to room temperature, and adjusting the pH value of both to 7.6 by using concentrated H_2SO_4 or NaOH, as necessary. One of the samples was clarified in the manner described in the solution spectrophotometric method (1); the remaining sample was left in the original unclarified state.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station.

Luminance Determination

The luminance values for each of the samples were determined by either the spectrophotometric method (1) or the filterphotometric method (2).

Calculation of Turbidity

The turbidity of the waste sample was calculated from

$$\text{Turbidity } (\%) = \frac{L_1}{L_2} \times 100$$

in which

L_1 = luminance of the waste sample containing suspended solids, and

L_2 = luminance of the filtered waste.

Expression of Results

The color of the suspended solids was expressed as follows:

Color Classification	Units	Unit
Hue (visual)	Blue, green, etc.	—
Turbidity	Per cent	0.1%

Example

A measured quantity (5 ml.) of a dicalite white filler solution was added to a 15-ml. aliquot of a clear dilute sulfite cooking liquor at pH 7.6. Another aliquot of the clear sulfite liquor was diluted with 5 ml. of distilled water to give the same concentration of colored material as in the first sample. A third sample was prepared by adding 5 ml. of white filler solution to 15 ml. of distilled water. The following luminance values were determined for the three samples:

Sample No.	Composition	Luminance %
1	Dilute sulfite liquor with S.S. (L_1)	32.4
2	Dilute sulfite liquor without S.S. (L_2)	61.0
3	Distilled water with S.S.	51.8

By substituting the luminance values from Samples 1 and 2 in the turbidity equation, the following value was calculated:

$$\text{Turbidity } (\%) = \frac{L_1}{L_2} \times 100$$

$$= \frac{32.4}{61.0} \times 100 = 53.1$$

The calculated value (53.1 per cent) is in close agreement with the actual turbidity value of 51.8 per cent.

Determination of Waste Concentrations in Stream Waters

The color characteristics of stream waters are governed by the visual light absorption properties of the water and the substances therein. On the basis of Beer's Law, it is relatively simple to calculate the concentration of a single waste solution in a receiving water.

At times it may also be of value to determine the concentration of each of several waste solutions in a stream water. Where the polluting wastes have highly characteristic light absorption properties, it is possible to adapt the principle of Beer's Law and form an equation which may be used for concentration calculations. The fundamental equation for a stream sample containing two waste solutions is:

$$x \log T_1 + y \log T_2 = \log T_3 \ldots . (1)$$

in which

x = fraction of waste 1 in the diluted mixture;

y = fraction of waste 2 in the diluted mixture;

T_1 = transmittancy of waste solution 1 at wavelength A;

T_2 = transmittancy of waste solution 2 at wavelength A; and

T_3 = transmittancy of stream water, containing wastes 1 and 2, at wavelength A.

By selecting two wavelengths at which to obtain the required transmittancy data, it is possible to develop two simultaneous equations with unknowns x and y. Upon solving the equations,

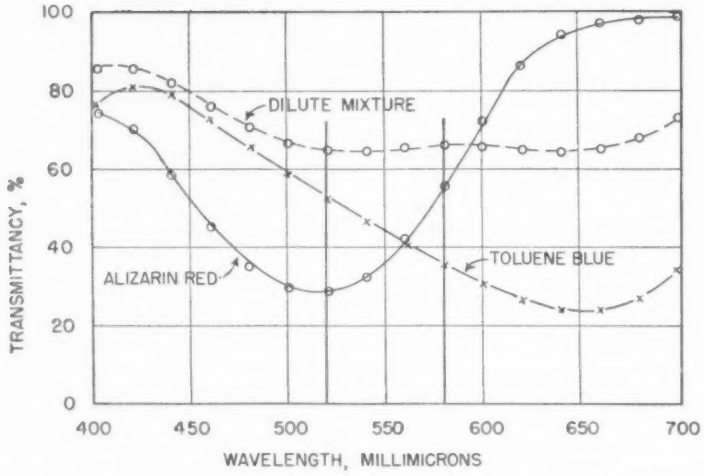

FIGURE 1.—Transmittancy curves for alizarin red and toluene blue mixtures at pH 7.0.

the actual concentration of each of the wastes at any point in the stream may be determined. In problems of this type, it is necessary to work with narrow spectral bandwidths, hence, a spectrophotometer is required for making the transmission determinations.

The procedure involved in this method is illustrated with a dilute mixture of alizarin red and toluene blue dye solutions. Known quantities of each of the dye solutions were added to a definite quantity of distilled water. The original samples and the dilute mixture were adjusted to pH 7 and filtered for spectrophotometric transmission determinations throughout the visual region from 400 to 700 mμ. To eliminate the possibility of color variation with pH, it is important to adjust the pH values of all solutions to a common value. Previous work (3) has shown that certain industrial wastes react in a manner similar to that realized with indicators, and color characteristics may vary considerably with changes in pH. The transmittancy curves for the dye solutions are shown in Figure 1. Transmittancy values were selected for each of the curves at the wavelength values 520 and 580 mμ., spectral bandwidths of 5 mμ. being used. The substitution of these values in Eq. 1 resulted in two simultaneous equations in terms of x and y. The equations were solved and the concentration data were as follows:

Sample No.	Constituent	Quantity Present (ml.)	Actual Vol. Conc. (%)	Calc. Vol. Conc. (%)
1	Toluene blue	15	30	29.0
2	Alizarin red	10	20	19.6
3	Distilled water	25	—	—

The accuracy of these calculations is dependent on the precautions that (a) all solutions must be adjusted to the same pH value and clarified before transmission determinations are made, and (b) the calculation transmission values must not be taken at wavelength values where the transmission curves coincide or have similar absorption characteristics.

To test this method with industrial wastes, known amounts of a yeast waste and a beet canning waste were mixed and diluted with a natural surface

water. The pH of the mixture was determined and the pH values of the waste solutions were adjusted to that of the mixture (conc. HCl or NaOH). The three wastes (yeast, beet, and mixture) were filtered for transmittancy determinations at wavelengths of 520 and 560 mμ., using spectral bandwidths of 5 mμ. The transmittancy values were substituted in Eq. 1 and the concentration values calculated, with the following results:

Sample Waste	Actual Conc. (%)	Calc. Conc. (%)
Beet	20.0	21.8
Yeast	10.0	9.3

The method may also be applied to solution mixtures containing more than two constituents. The complexity of the mathematics involved becomes increasingly greater, however.

Since the accuracy of the method is affected by changes in the light absorption characteristics of the constituents, it should be realized that several influencing factors are present in stream waters under normal conditions. The color characteristics may be altered by sunlight, chemical reaction between wastes, adsorption, biological action, and other factors.

Projection of Color Characteristics to Various Depths and Concentrations

The projection of industrial waste color characteristics (1-cm. cell) to stream conditions is a difficult problem. The calculations necessary to compensate for concentration and depth changes are not very involved. In converting to data which express the actual color appearance as observed in the stream, the following factors must also be considered: (a) type of day (clear, cloudy, etc.), (b) time of day, (c) angle of observer's view (directly overhead, shoreline, etc.), (d) light absorption by stream bottom, (e) light absorption and reflection by suspended matter, (f) light absorption by surrounding objects (trees, bushes, etc.), and (g) wind action.

When these factors are considered, it is apparent that the value of extending laboratory waste color data to appearance of the stream is limited. First, the light source is not constant and varies with the time and type of day. Such variation results in change in appearance of any object in the light rays.

Since the light absorption by a stream is a function of the depth, the appearance depends upon the position of the observer with respect to the stream. If the observer is directly overhead, the length of light passage through the water is at a minimum, but should the observer be standing on the shoreline, the "effective depth" of the stream water might be considerably greater. Light absorption by the stream bottom, the surrounding trees, bushes, etc., are other factors which increase the degree of light absorption between the light source and the observer, and as a result affect the appearance of any object in the light energy path. The effect of silt in stream waters following a heavy rainstorm is commonly observed and the importance of considering suspended matter in connection with stream color characteristics is obvious. Silt or clay may completely mask the color of a stream water containing an industrial waste. In view of the numerous factors involved, it appears that standards based on actual stream conditions are not feasible for the control of color pollution.

A more feasible alternate method of approaching the problem is to use longer light absorption cells for stream waters than those used for industrial wastes. Longer cell lengths would be required to obtain effective transmission data because of the relatively low concentration of light absorbing substances.

Whether projecting the laboratory industrial waste (1-cm. cell) color data to actual stream conditions or to longer absorption cells, the problem may be

TABLE I.—Color Characteristics of a Sulfite Cooking Liquor Waste at Various Concentrations

No	Ratio of Raw Waste to Total	Relative Concentration	Color Characteristics		
			Dominant Wavelength (mμ.)	Luminance (%)	Purity (%)
1	1:2	144	589	6.0	100
2	1:4	72	584	18.5	100
3	1:6	48	582	31.1	72
4	1:12	24	578	55.2	46
5	1:24	12	576	72.7	26
6	1:60	5	574	87.6	9
7	1:144	2	573	93.8	5
8	1:288	1	573	96.7	2

solved in the same basic manner. The following example illustrates a proposed method for projecting 1-cm. absorption cell color characteristics of a sulfite cooking liquor waste to 20-cm. absorption cell color data. This method is of value for calculating the degree of dilution or color reduction necessary to satisfy stream standards based on a 20-cm. absorption cell.

Procedure

Samples of a sulfite cooking liquor waste were diluted to various concentrations, adjusted to pH 7.6, and filtered for color determinations (1-cm. cell). The resulting data are given in Table I and Figures 2 and 3. If the values of the negative log of luminance for various concentrations of the sulfite liquor conformed to Bouger's Law ("Each layer of equal thickness absorbs an equal fraction of the light which traverses it.") and Beer's Law ("The absorption of light by a solution is directly proportional to the concentration of the absorbing material in solution."), it would be a relatively easy matter to convert luminance values from one set of conditions to another with respect to concentration and depth.

Any waste solution following these laws would have a linear relationship between the concentration and the negative log of the luminance of the waste solution. The negative log luminance—concentration curve (Figure 2) is almost a straight line, and values for any specified concentration might be calculated to other conditions with a reasonable degree of accuracy. However, the curve is not a straight line, and because the diluting water obtained from a stream above the water outfall may not be clear, it is advisable to resort to the type curves illustrated in Figure 3.

To calculate the degree of waste color reduction treatment necessary to meet stream standards (20-cm. cell), it is necessary to have the color specifications (1-cm. cell) for the industrial waste, the length of the stream-water

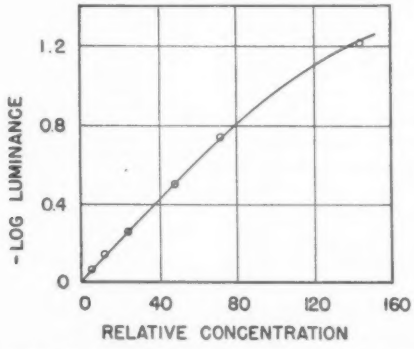

FIGURE 2.—Relationship of concentration and negative log of luminance for a sulfite waste liquor.

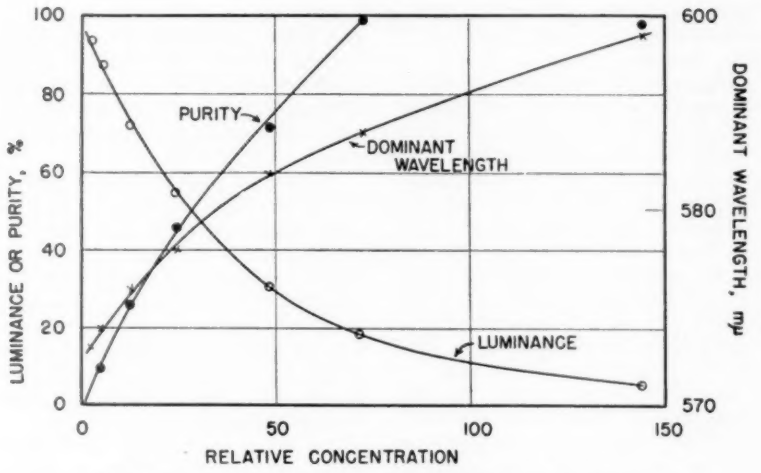

FIGURE 3.—Color characteristics of a sulfite cooking liquir waste at various concentrations.

light absorption cell, and the degree of dilution of waste in the receiving stream.

In problems involving solutions, the depth of solution and concentration factors are inversely related to each other. In other words, a solution that is diluted 20 times appears the same at a 20-cm. depth as a sample of the undiluted waste at a 1-cm. depth. The following example illustrates an application of the foregoing principle:

Data—Sulfite Liquor (pH 7.6)

1. Luminance value (1-cm. cell) = 40 per cent.
2. Length of stream-water absorption cell = 20 cm.
3. Dilution factor for waste in stream = 30.
4. Desired luminance value in stream-water light absorption cell (20 cm.) = 70 per cent. (This value may be considered as the stream standard.)

Problem—

To determine the degree of color reduction necessary to provide a 20-cm. absorption cell luminance value of 70 per cent after the waste has been diluted in the stream water. The problem is solved by substituting in

$$A = \frac{BE}{C} \quad \ldots\ldots\ldots (2)$$

in which

A = relative concentration factor (Figure 3) corresponding to the desired 1-cm. luminance value after color reduction treatment;

B = dilution factor (ratio of total volume after dilution in stream to volume of waste);

C = length of light transmission path through the stream-water transmission cell, in cm.; and

E = relative concentration value (Figure 3) corresponding to the stream standard luminance value.

Substituting in Eq. 2,

$$A = \frac{30 \times 14}{20} = 21.$$

The luminance value corresponding to 21 is 60 per cent (Figure 3). Thus, the 1-cm. luminance value (40 per cent) must be increased to 60 per cent by color reduction treatment so that the

20-cm. cell stream standard luminance value (70 per cent) may be obtained after dilution.

Establishment of 20-cm. absorption cell standards would be governed by the luminance value and by the purity and dominant wavelength values. For example, the 70 per cent luminance value (20-cm. cell) in the preceding problem indicates purity and dominant wavelength values of 28 per cent and 576 mμ., respectively (Figure 3). The color standards are determined by considering all three characteristics with respect to individual standards. The limiting characteristic determines the luminance value to be used. In other words, the 20-cm. cell color characteristics after dilution and treatment must be such that each of the color values (dominant wavelength, luminance, and purity) falls within its specific standard. The 20-cm. stream cell length was selected as an approximation and should not necessarily be accepted as a final recommended standard.

Summary

A study was made for the purposes of (a) developing a method for expressing the effect of suspended matter on the color characteristics of industrial wastes, (b) using industrial waste light absorption properties for calculating the concentration of industrial wastes in stream waters, and (c) investigating methods for projecting industrial waste color characteristics to stream conditions.

A method is presented for expressing the color characteristics of industrial waste suspended solids in terms of the visual hue and the degree of light absorption effected solely by the suspended matter. The principle of Beer's Law was adapted to the light absorption properties of polluted stream waters for the purpose of calculating the concentration of two or more contaminating wastes.

The direct projection of industrial waste color characteristics to actual stream conditions is not feasible. However, these color characteristics may be extended to longer light absorption cells which are more suitable for stream-water standards.

Acknowledgment

This investigation was supported by a research grant from the Division of Research Grants and Fellowships, National Institutes of Health, U. S. Public Health Service.

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CHLORINE ORDER M-31 REVOKED

Effective November 18, 1952, National Production Authority Order M-31 was revoked. This order provided for equitable distribution of defense-rated orders among chlorine producers and assured chlorine supplies for public health needs. Revocation of the order was possible because current chlorine production is adequate to fulfill all military and civilian needs.

WHITE WATER TREATMENT *

IV. Mesophilic and Thermophilic Digestion

By Willem Rudolfs and Herman R. Amberg

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In white water clarification, sludge disposal becomes a major problem because of inability to re-use the sludge in the furnish. Since a number of paper mills discharge their wastes to municipal sewage treatment plants, it is of practical interest to know the effects, if any, upon the digestion units.

White water sludge after 24-hr. settling has a concentration of about 2 per cent; it is difficult to concentrate by prolonged storage (1). The volatile constituents of paperboard sludge constitute about 80 per cent of the dry weight of the sludge. Digestion of this sludge under mesophilic and thermophilic conditions was started with four aims in mind: (a) concentration of the sludge, (b) stabilization of the organic material, (c) the relative efficiency of high and low temperature, and (d) the feasibility of handling board mill sludge at municipal sewage treatment plants.

Methods and Materials

The paperboard sludge used for these experiments was obtained by settling white water for 24 hr. and decanting the supernatant liquor until a sludge concentration of approximately 2 per cent was obtained.

Digesters seeded with ripe sewage sludge, incubated at 36° C. and 50° C., received daily additions of white water sludge which were gradually increased. Daily withdrawals were composited for a week and solids were determined on the composite sample. To simulate common digester operation practice, supernatant liquor was withdrawn whenever possible to concentrate the sludge. Average analyses of the seed and feed were as follows:

	Seed Sludge	White Water Sludge
pH	6.70	6.63
Total solids (%)	6.50	2.10
Volatile sol. (%)	57.4	82.8
Ash (%)	42.6	17.2

Ammonia was added to the daily increments in the form of ammonium carbonate, raising the pH of the feed from 6.60 to 8.40. The quantity of nitrogen added was sufficient to obtain a carbon to nitrogen ratio of 40 (based on volatile solids). Gas readings were taken daily. Some gasification of the seed sludge took place, but ceased after two weeks of digestion.

Results

The results of 9 additional weeks of digestion are summarized in Table I, where the average weekly composite analyses of the digester contents are shown.

The total solids concentration increased gradually with increased loadings, accompanied by an increase in the percentage of volatile solids. In other words, volatile solids destruction decreased when the loadings were gradually increased from 0.08 to 0.16 lb. of volatile solids per cubic foot of digester capacity per day. The feed sludge, having an initial concentration of about 2 per cent, was concentrated to nearly 12 per cent under mesophilic conditions and to 8.5 per cent under the thermo-

* Paper of the Journal Series, New Jersey Agricultural Experiment Station.

TABLE I.—Analyses of Mesophilic and Thermophilic Digester Contents at Various Intervals

Determination	Digestion Period									
	Initial		5 Weeks		7 Weeks		8 Weeks		9 Weeks	
	Mes.	Therm.	Mes.	Therm.	Mes.	Therm.	Mes.	Therm.	Mes.	Therm.
Total sol. (%)	6.50	6.50	7.61	6.26	7.49	6.81	9.24	8.13	11.72	8.50
Vol. sol. (%)	57.4	57.4	61.6	61.0	63.6	63.6	65.5	65.2	67.5	68.2
Ash (%)	42.6	42.6	38.4	39.0	36.4	36.4	34.5	34.2	32.5	31.8
Sludge vol. (ml.)	3,000	3,000	2,700	3,000	2,740	2,960	2,580	2,860	2,585	3,000

philic conditions. Of interest is that the 12 per cent sludge had gel-like characteristics, flowing with difficulty.

At mesophilic temperatures with a volatile matter loading of 0.1 lb. per cu. ft. per day, the volatile matter destruction amounted to 56 per cent as compared to 39 per cent at thermophilic temperatures (Table II). With higher loadings the rate of volatile matter destruction decreased rapidly. The loadings obtained under mesophilic conditions compared favorably with efficiency values obtained for sewage sludge digestion.

The effect of loading on gas production under mesophilic and thermophilic conditions (Table III) is similar to the effect on volatile matter destruction; however, the gross effect on gas production is less on volatile matter reduction.

It appears, therefore, contrary to experience with sewage sludge, that digestion of board mill sludge is feasible under mesophilic conditions and more effective than under thermophilic conditions. Undoubtedly, paperboard mill sludge can be handled in sewage treatment plants if sufficient digestion capacity is available. However, on a volatile matter basis, mixtures of board mill sludge and sewage sludge will produce less gas than with sewage sludge alone. Approximately 3.5 to 5 cu. ft. of gas can be expected per pound of volatile matter in board mill sludge at loadings similar to those practiced for effective sewage sludge digestion. Since gas production and volatile matter destruction are less than for sewage sludge, accumulation of solids residue is greater. Hence, digested sludge dewatering or drying facilities must be increased.

Digestion of paperboard mill sludge alone under mesophilic conditions brings about two desired features; namely, destruction of organic matter, and sludge concentration. The digested board mill sludge can be readily dried without creating nuisances. Perhaps the most important feature of board

TABLE II.—Solids Destruction (Per Cent)

Vol. Sol. Added (lb.)[1]	Det. (days)	Mesophilic		Thermophilic	
		Tot. Sol.	Vol. Sol.	Tot. Sol.	Vol. Sol.
0.0807	16	—	—	—	—
0.0889	11	55.5	65.4	44.9	48.8
0.1023	9.6	49.5	56.0	30.4	39.1
0.1460	8.5	19.5	27.6	21.2	31.6
0.1595	7.7	7.0	21.1	10.8	16.2

[1] Pounds per cubic foot capacity per day.

TABLE III.—Loadings, Gas Production, and pH

Vol. Sol. Added (lb.)[1]	Gas Production (c.c./g.)[2]		pH	
	Mes.	Therm.	Mes.	Therm.
0.0807	383	276	6.80	7.00
0.0889	300	275	6.90	7.10
0.1023	296	270	6.80	7.00
0.1460	201	218	6.70	6.80
0.1595	136	137	6.65	6.70

[1] Pounds per cubic foot per day.
[2] Cubic centimeters per gram of volatile solids added.

mill sludge digestion is reduction in volume. It is difficult to concentrate paperboard mill sludge to more than 2 per cent solids by plain settling, compaction, or by use of chemicals, but with digestion the waste readily concentrates to several times its original concentration. In effect, this means that the troublesome sludge disposal problem would be materially less. For instance, the volumes of sludge produced by settling, flocculation, and chemical coagulation may vary from 60,000 to 90,000 gal. per million gallons of waste. Digestion, with rising loadings of about 0.1 lb. volatile matter per cubic foot of digester capacity, reduces these volumes to 15,000 to 20,000 gal. Such sludge presents no difficulty in pumping.

The digestion capacity required is appreciable. For a 100-ton paper mill, assuming 1 m.g. of white water with a settleable volatile solids content of 375 p.p.m., the approximate digestion capacity required would be 31,200 cu. ft. Gas production would amount to about 4.1 cu. ft. per pound of volatile matter added, or about 12,800 cu. ft. of gas per million gallons of white water. Gas analyses show that the heat value of the gas produced daily would amount to about 8,300,000 B.t.u.

Conclusions

The results obtained warrant the following conclusions:

1. Mesophilic digestion of board mill paper waste sludge is feasible and better than digestion under thermophilic conditions for stabilization of organic matter.

2. With volatile matter loadings of 0.1 lb. per cubic foot of mesophilic digester capacity per day, about 55 per cent of the volatile matter is destroyed, producing about 4.1 cu. ft. of gas per pound of organic matter added.

3. The volume of sludge is reduced greatly and sludge concentrations of about 8 per cent can be produced without difficulties in handling.

4. Paperboard mill sludge does not interfere with sewage sludge digestion provided sufficient capacity is available.

Summary

In white water clarification, sludge disposal is a major problem because some mills are unable to use this sludge in their furnish.

Laboratory studies show that paperboard mill sludge can be digested readily and can be handled by sewage treatment plants if sufficient capacity is available. On a volatile matter basis, mixtures of board mill sludge and fresh sewage solids will produce less gas than will the sewage solids alone, because white water sludge produces less gas than do sewage solids. Thermophilic digestion appears less effective than mesophilic digestion. Mesophilic digestion decreases the sludge volume materially by volatile matter destruction and changes in water-holding capacity of the sludge, which allows better compaction.

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Stream Pollution

THE OXYGEN RESOURCES OF SAN DIEGO BAY

By Isadore Nusbaum and Harold E. Miller

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The San Diego Regional Water Pollution Control Board, recognizing the economic and recreational importance of San Diego Bay to that region, in 1950 requested the California Departments of Public Health and of Fish and Game to undertake a survey of the bay. The survey was to establish the existing water quality, the sources of municipal and industrial wastes, the beneficial uses and the effect of the wastes on these uses, the location and extent of sludge deposits, and the effect of the sludge deposits on marine life. The data received from these surveys were to be used in establishing long-range objectives for the water quality in San Diego Bay and to prescribe waste disposal requirements to attain these objectives. The surveys, conducted in 1951 and completed in 1952, presented voluminous data covering bacterial contamination, dissolved oxygen concentrations, waste loadings, and sludge deposits, and their effect on benthic marine invertebrates. It became necessary as part of the over-all investigation for the Regional Board to undertake a study, partially based on these data, to determine the availability of oxygen for the stabilization of readily oxidizable waste material. Such a determination of the oxygen resources would be invaluable in establishing the extent to which San Diego Bay could continue to be utilized more or less indiscriminately for the disposal of wastes.

It was easily recognized that there would be three primary sources for the reoxygenation of the bay, as follows:

1. Reaeration from the atmosphere. A hypothetical steady state of oxygen depletion was assumed to exist, the assumed minimum oxygen concentration to be based on that permitted by the long-range objectives for water quality in the bay.

2. The oxygen produced in the water by the chlorophyll-bearing phytoplankton found in the bay.

3. The oxygen brought into the bay by the oxygen-saturated ocean waters entering on each tidal flood. The calculation was to be based on the excess of oxygen present in the flood waters over the minimum discussed under point 1.

The San Diego Bay estuary is characterized by a lack of stream flow into the bay except during a short rainy season. The only fresh water discharged at regular intervals is the volumetrically insignificant municipal and industrial waste waters. Thus, the foregoing represent the only major sources of oxygen to the bay.

Reaeration from the Atmosphere

Phelps (1) has developed an expression for the reaeration of natural waters from a consideration of Fick's Law of Hydro-Diffusion, which may be simply expressed as

$$\frac{dm}{dt} = - D_L A \frac{dc}{dy} \quad \ldots\ldots (1)$$

in which

$\frac{dm}{dt}$ = the rate of mass transfer;

D_L = the molecular diffusivity;

A = the area across which diffusion is taking place; and

$\frac{dc}{dy}$ = the concentration gradient in the direction of diffusion.

Upon integration, Phelps obtained

$$D_t = D_a \times 0.811 \times \left(e^{-K} + \frac{e^{-9K}}{9} + \frac{e^{-25K}}{25} + \dots\right) \quad (2)$$

in which

$$K = \frac{\pi D_L t}{4L^2} \quad (3)$$

D_a = initial D.O. saturation deficit;

D_t = the deficit after time t; and

L = depth.

It should be thoroughly understood that Fick's Law defines only the molecular diffusivity (that is, the only motion involved is due to molecular agitation) and for essentially all practical conditions represents a set of ideal circumstances rarely approached. The diffusivity or coefficient of diffusion has the dimensions of length^2/time, as shown by a dimensional analysis of Eqs. 1 and 3. The law is not concerned with the process of solution, but merely with the process of diffusion of a substance in solution.

Based on an experimental determination of the diffusion coefficient, Phelps arrived at a value of 1.42 sq. cm. per hr. (0.00153 sq. ft. per hr.) at 20° C. This is in complete disagreement with the coefficient of diffusion for oxygen in water reproduced in the International Critical Tables (2), which is 0.0713 sq. cm. per hr. (0.000077 sq. ft. per hr.) Adeney (3) has pointed out some of the discrepancies in the formulation by Black and Phelps, but with little acceptance of the criticism by Phelps. With the present state of knowledge, it becomes evident that the data obtained by Phelps measures the combined effects of molecular and eddy diffusion and of solution upon the system used in the experiment.

Phelps has applied Eq. 2 using the previously mentioned "diffusion" coefficient with apparent success. However, there are at least two obvious sources of error in the equation for the exponent K, which controls the value of the reaeration. These are t, the time of exposure, and L, the depth of the layer under consideration. The values of L and t are arbitrarily assigned to obtain values which conform to experimentally determined data. Fick's Law, as noted, applies only to molecular diffusion and pure molecular diffusion can apply only under conditions of laminar flow. Laminar flow, however, is rarely encountered in nature and turbulent flow, or turbulence, normally prevails. The concept of eddy diffusion has been used to describe the extremely rapid rate of dissemination of a solute in a solvent. The process cannot be entirely a function of nuclei dispersed by turbulence and from which molecular diffusion takes place, as described by Phelps.

Streeter and Phelps (4) derived an expression for the rate of atmospheric reaeration from the differential equation

$$-\frac{dD}{dt} = K_2 D \quad (4)$$

which states that the rate of decrease in oxygen saturation deficit is proportional to the deficiency D. Integration of Eq. 4 yields

$$D_t = D_a e^{-k_2 t} \quad (5)$$

or, expressed in common logarithms,

$$D_t = D_a 10^{-k_2 t} \quad (6)$$

in which

$$K_2 = 2.303 k_2 \quad (6a)$$

K_2 or k_2 may be designated as the reaeration coefficient and has the dimensions of t^{-1}. The value of k_2 has been

calculated for natural waters by observations on the stream under consideration and substitution in Eq. 6 or some variation thereof, or by the use of the equation for the oxygen "sag" curve. Either method is subject to extreme errors, as the coefficient calculated actually measures all biological, chemical, and physical factors affecting reaeration at the particular time of measurement on the individual body of water. The method appears to be most applicable to flowing streams and less so to tidal estuaries. The limitations of the method can be noted by examining the reports on the Ohio and Illinois Rivers, in which application was attempted. The data are particularly characterized by their inconsistencies. It should be evident that the physical phenomena of absorption of oxygen in water cannot be more or less rigorously determined on natural waters where the biological factor, for example, has an important effect on the data obtained for the determination. Subsequent investigations of the Ohio (5) and Scioto Rivers (6) have made little use of the coefficient k_2 and have expressed the results in terms of r_a, the rate of surface reaeration in pounds per 1,000 sq. ft. per day.

The absorption of a gas in a liquid as a case of the transfer of material between phases has been given serious consideration in the field of chemical engineering. An excellent review of current knowledge and bibliography has been written by Sherwood and Pigford (7). Lewis and Whitman (8) proposed the two-film theory of mass transfer between phases. In the absorption of a gas by a liquid or in the extraction of a solute from a liquid by a second liquid immiscible with the first, the solute must diffuse out of one fluid and into the other fluid phase. Two films were visualized, one in each phase, through which the solute must diffuse in series. The "film concept" postulated a condition of laminar flow in the boundary films through which the material passed by molecular diffusion. This concept, which has been useful in supplying a simple picture of a complicated process, has been misleading in that there is a transition from laminar to turbulent flow in the phase boundary and the resistance to transfer is due to both molecular and eddy diffusion. It should be emphasized that although the film theory is almost 30 years old and has been applied to many design problems, it has never been completely established but has proven a convenient method of analysis. Because the relative importance of eddy diffusion and molecular diffusion in the over-all process of transfer is not known, the unknown diffusivity and the length of the diffusion path are lumped together in the form of a coefficient, k_L, defined (7) by

$$N_A = k_L(c_i - c) \quad \ldots\ldots (7)$$

in which

N_A = the rate of mass transfer, $\frac{\text{lb.}}{\text{hr.ft.}^2}$ or $\frac{\text{g}}{\text{hr.cm.}^2}$;

k_L = the liquid film coefficient, $\frac{\text{lb.}}{\text{hr.ft.}^2\left(\frac{\text{lb.}}{\text{ft.}^3}\right)}$ or $\frac{\text{g}}{\text{hr.cm.}^2\left(\frac{\text{g.}}{\text{cm.}^3}\right)}$;

c_i = the concentration at the phase boundary, $\frac{\text{lb.}}{\text{ft.}^3}$ or $\frac{\text{g}}{\text{cm}^3}$; and

c = the concentration in the body of the liquid.

Similarly, for the gas phase

$$N_A = k_G(p_i - p) \quad \ldots\ldots (8)$$

in which

k_G = the gas film coefficient, $\frac{\text{lb.}}{\text{hr.ft.}^2\text{(atm.)}}$ or other consistent units;

p_i = the partial pressure of the diffusing gas at the phase boundary, in atmospheres; and

p = the partial pressure of the diffusing gas in the main stream, in atmospheres.

Then

$$N_A = k_G(p_i - p) = k_L(c_i - c) \ldots (9)$$

or

$$N_A = K_G(p - p_e) = K_L(c_e - c). (10)$$

in which

K_G and K_L = over-all mass transfer coefficients (units as for k_G and k_L);

p_e = the partial pressure of the solute gas in equilibrium with c; and

c_e = the concentration of the solute in liquid in equilibrium with p.

In the case of a relatively insoluble gas (such as oxygen or nitrogen in water) it has been shown that the liquid film resistance is large in comparison with the gas film resistance and the liquid film is said to be controlling. Experimental data in this case are generally reported in terms of K_L.

Thus far only the physical absorption and solution of a gas in a solvent under steady state conditions have been considered. Actually, the absorption of oxygen from the atmosphere in polluted waters represents an unsteady state that presumably is affected by the first-order reaction which takes place in satisfying the B.O.D. The expression which results under these conditions is quite complicated and difficult of solution. Fortunately, in the case of a very slightly soluble gas (such as oxygen in water) and where the reaction rate constant is low (as in the B.O.D. reaction), the situation may be resolved into a consideration of steady state absorption and the expression is reduced to

$$N_A = K_L(c_e - c) \ldots\ldots (10)$$

It was decided to attack the problem of atmospheric reaeration of surface waters in terms of K_L, the over-all coefficient of mass transfer, and to correlate available data in terms of the mass transfer coefficient. From an analysis of the dimensions of K_L and Eq. 10 it is apparent that the absorption of oxygen in water under natural conditions is primarily a function of the area of the water surface exposed and the oxygen concentration in solution, and is affected by the temperature, the salinity of the water, the velocity, and the turbulence.

The over-all coefficient of mass transfer, K_L, is related to Streeter's reaeration coefficient, K_2. This may be demonstrated by a dimensional analysis of the related equations. The relationship is

$$K_2 = \frac{K_L}{H} \ldots\ldots\ldots (11)$$

in which H is the depth of the fluid. Actually, by relating K_2 to Adeney's f, the escape coefficient (9) which was shown to be the same as the mass transfer coefficient (10), the following results:

$$K_2 = K_L \frac{A}{V} \ldots\ldots\ldots (12)$$

in which A = area, and
V = volume.

$\frac{A}{V}$ is the expression for the area of interchange available per unit volume in any vertical section selected and K_2 is comparable to $K_L a$, frequently encountered in absorption problems on packed towers, where a is the area of surface per cubic foot of packed volume.

Streeter (11) subsequently published the results of an extensive series of experiments on the reaeration of deaerated water in an artificial channel. It was possible to calculate K_L (Table I) from the data presented and to prove the relationship between K_2 and K_L.

Based on the data obtained by Streeter (11) and Kehr (12) in an experimental channel operated at 12 in. depth of flow and at velocities up to 47 ft. per min. with deaerated water, K_L was calculated. The plotted values (Figure 1) show that the rates of reaeration obtained with the experimental channel are far in excess of those obtained in natural waters in the limited data that are available, which include a biological factor. It is also necessary

to include some parameter of turbulence in comparing or analyzing the data from natural waters with the experimental channel curve. As noted from the data, K_L varies directly as V. Below approximately 5 ft. per min. the slope of the curve changes. This has been attributed to a change in the flow characteristics from turbulent to laminar. It is probably more nearly correct to say that in the mechanism of mass transfer for this range of velocities the principal resistance is due to molecular diffusion, rather than a combination of molecular and eddy diffusion and any other factors, such as surface effects of dispersed substances.

It becomes quite difficult to evaluate the parameters of turbulence which might be used to correlate the experimental data. Little success was attained in attempting to correlate the data with the Reynolds dimensionless number and with combinations of several pertinent dimensionless numbers. However, comparison of K_L for the experimental channel with some of the data available for natural channels indicates that K_L varies directly as F, the Froude number, which may be simply expressed as

$$F = \frac{V}{\sqrt{gL}} \quad \ldots\ldots\ldots (13)$$

in which

V = the velocity;

L = a typical linear dimension of flow; and

g = the gravitational constant.

The hydraulic radius, R, appears to be the logical linear dimension to use, since it is descriptive of the boundary conditions of the flow system. A considerable amount of additional investigation and data are necessary to establish this material on a firmer basis. The following proportionality may then be used to calculate K_L for other open channel systems of fairly regular shape:

$$K_L \propto \frac{V}{\sqrt{gR}} \quad \ldots\ldots\ldots (14)$$

and

$$\frac{(K_L)_1}{(K_L)_2} = \frac{V_1\sqrt{R_2}}{V_2\sqrt{R_1}} \quad \ldots\ldots (14a)$$

For the experimental channel used by Streeter (11) the hydraulic radius is equal to 0.2 ft.

K_L varies with the temperature, and for the purposes of this study all coefficients were corrected to 20° C. Haslam, Hershey, and Keen (20) have shown that when the gas film resistance is very small compared with liquid film resistance, changes in the former may be neglected in calculating the effect of changes in the latter upon the over-all coefficient. The case of negligible gas film resistance as compared to the liquid film resistance applies to the transfer of oxygen from air to water. Haslam *et al.* (20) found that k_L, the liquid film coefficient, varied as the fourth power of the absolute tempera-

TABLE I.—K_L, Over-All Coefficient of Mass Transfer, Calculated from References (11) (12)

Mean Velocity (ft./min.)	Mean Temp. (° C.)	r_0	K_L	
			Calc.	at 20° C.
21.5	20	0.000103	11.2	11.2
5.0	25.5	0.0000151	1 82	1.69
10.4	25.5	0.0000430	5.19	4.82
20.9	25.3	0.000105	12.6	11.7
23.1	26.0	0.000119	13.8	12.7
28.8	25.7	0.000154	18.7	17.3
4.3	24.2	0.0000143	1.59	1.51
8.8	23.7	0.0000336	3.92	3.73
13.8	21.0	0.0000591	6.59	6.50
20.0	20.3	0.0000933	10.1	10.1
22.1	20.3	0.000105	11.5	11.5
24.0	20.5	0.000114	12.5	12.4
2.6	12.0	0.0000125	1.15	1.28
3.3	14.3	0.0000146	1.40	1.50
6.9	14.7	0.0000220	2.16	2.31
14.0	15.7	0.0000510	5.10	5.38
14.0	18.7	0.0000538	5.66	5.75
23.8	14.0	0.000115	11.05	11.9
6.0	21.0	0.0000175	1.95	1.92
9.3	23.0	0.0000352	4 05	3.89
18.0	26.0	0.0000835	10.3	9.52
24.5	20.0	0.000116	12.6	12.6
34.0	20.0	0.000168	18.3	18.3
47.0	25.0	0.000225	26.8	25.1

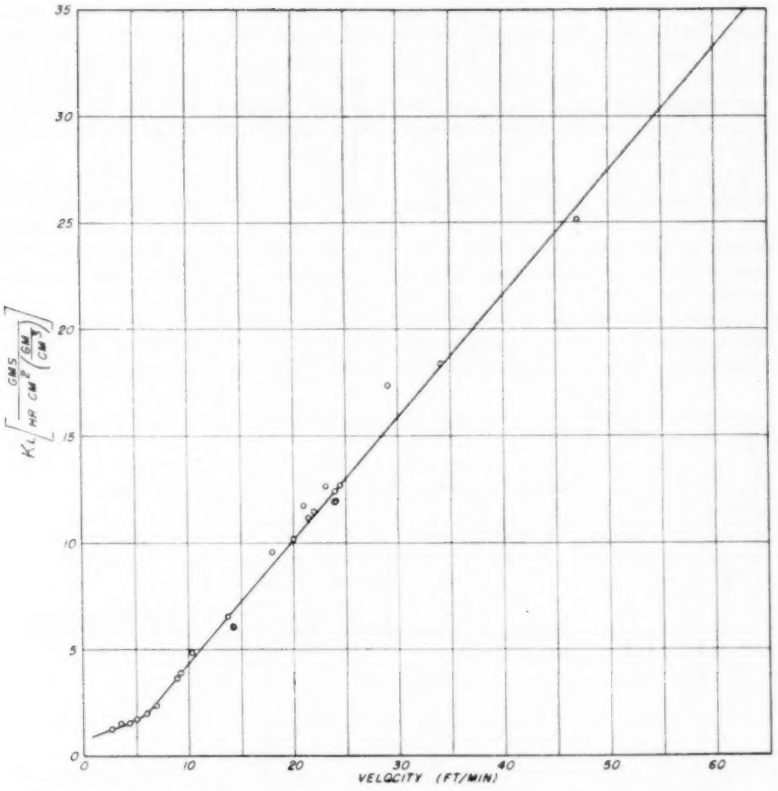

FIGURE 1.—Relation of coefficient of mass transfer and velocity of flow, from Ref. (11) and (12).

ture and this relationship was used in obtaining the value of K_L at 20° C. The temperature correction then becomes

$$(K_L)_{t^\circ C.} = (K_L)_{20^\circ C.} \left(\frac{T}{293}\right)^{4.0} \quad (15)$$

in which

K_L = the over-all coefficient of mass transfer, and

T = the temperature, ° K.

Application of Data

The application of these data for the determination of the physical rate of atmospheric reoxygenation to streams would appear to be fairly simple. The problem which arose was the calculation of the rate of solution of atmospheric oxygen in a tidal estuary of the neutral type having a highly irregular shape and depth, which is certainly an extreme case of unsteady, nonuniform flow. The neutral type of estuary is defined as one in which neither fresh-water inflow nor evaporation dominates. This is true of San Diego Bay, where the fresh-water input to the bay, essentially domestic and industrial wastes, is counterbalanced by the evaporation losses. The mean annual precipitation is about 10 in. and no

prolonged periods of low salinity are found in the bay. The major portions of the watersheds of the Sweetwater and Otay Rivers, the principal drainage basins discharging to the bay, are dammed for water supply purposes. The rivers are normally dry runs.

To permit the use of the data presented herein, the condition of flow in the bay must be converted to that of steady uniform flow. Since the direction of the current is unimportant in its effect on the absorption of oxygen, and since in San Diego Bay both wind and tide play important parts in the circulation of water within the estuary, the velocities of flow used were calculated as the mean tidal velocity. This assumes that the net over-all circulation within the bay is equivalent to that resulting from a mean uniform flow equal to the mean velocity resulting from a mean tidal range.

The bay was also divided into three major areas of more or less uniform depth and use (Figure 2). The mean depth used was the mean lower low tide (m.l.l.w.) elevation plus one-half the mean tidal range of 4.2 ft.

Areas were determined with a polar planimeter on Chart 5107, San Diego Bay, U.S.C. & G.S., revised May 14,

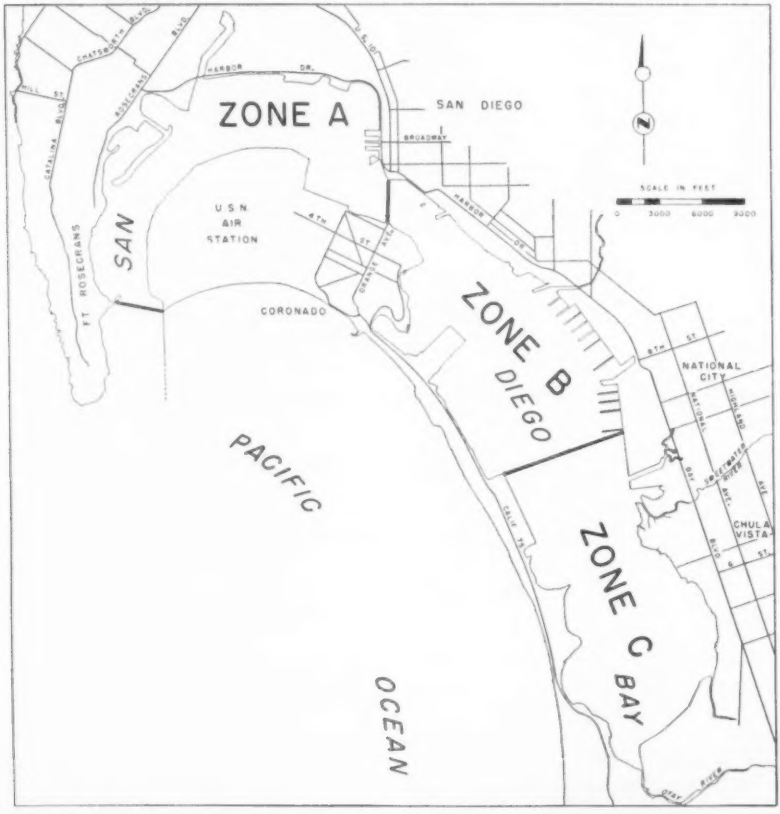

FIGURE 2.—Divisions of San Diego Bay for oxygen resources study.

TABLE II.—Atmospheric Reoxygenation of San Diego Bay

Zone	Area (sq. ft. ×10⁶)	Mean Depth (ft.)	Mean Velocity (ft./min.)	K_L at 20° C.	N_A at 20° C. (lb./acre-day)		Avail. O_2 (lb./day)
					0.0 Sat'n	4.0 p.p.m.	
A	144	37	53	2.20	35	16.1	53,000
B_1	76.5	32	30	1.31	21	9.7	17,100
B_2	102.5	12	19	1.34	21.4	9.9	23,200
C	161.5	7	15	1.45	23	10.6	39,400
Total	—	—	—	—	—	—	132,700

1951. The area of Section A at the north end of the bay from the entrance at Ballast Point to Ferry Crossing, was taken as 144,000,000 sq. ft. at a depth of 37 ft. Area B was divided into two sections, one with a mean depth of 12 ft. and an area of 102,500,000 sq. ft., and the other with a depth of 32 ft. and an area of 76,500,000 sq. ft. Area C was considered to have a mean depth of 7 ft. and an area of 161,500,000 sq. ft. Based on the mean tidal range of 4.2 ft., the mean velocity in Area A was 53 ft. per min.; in the 10-ft. depth of Area B, 19 ft. per min.; in the 30-ft. depth of Area B, 30 ft. per min.; and in Area C, 15 ft. per min.

Table II is a compilation of the data for the atmospheric reoxygenation of San Diego Bay at a temperature of 20° C. The mean summer and winter temperatures in San Diego Bay are not appreciably different from 20° C. Since this is by no means an exact or precise calculation, but is intended to indicate the order of magnitude of the data, the values indicated in Table II can be used for all seasons. The final values are based on a permissible reduction of the dissolved oxygen to 4.0 p.p.m.

It should be observed that K_L is assumed to be the same for saline water as it is for fresh water. Available data are somewhat variable on this point. The controlling factor in the difference between fresh and sea water is the lower solubility of oxygen in the saline water.

Mention should also be made of the decreased rate of reoxygenation of water under turbulent flow conditions in the presence of many substances commonly found in wastes and polluted waters (12). The tendency of such materials to accumulate in the interfacial "film" leads to an, as yet, undetermined source of interference with mass transfer. This interference cannot merely be attributed to the effect upon the interfacial tension of the system since it has been found that substances giving the same amount of interfacial tension depression per unit concentration frequently caused different rates of absorption or evaporation.

Oxygen Produced by Chlorophyll-Bearing Phytoplankton

Probably the most important source of oxygen available for the oxidation of pollution in San Diego Bay results from the activity of the chlorophyll-bearing phytoplankton. That the chlorophyll-bearing flora may contribute appreciable amounts of dissolved oxygen to a body of water has been recognized by many sanitary engineers (13). Little effort has been made to evaluate this source of oxygen when making an oxygen balance on a particular body of water, although the importance of obtaining such data was indicated in a recent publication (14). Oceanographers (15) have frequently used techniques similar to those developed by Abbott (14) in obtaining in-

formation concerning micro- and macrobiological activity in the oceans and their connecting waters. Attempts to determine the rate of atmospheric reaeration without taking under consideration biologic activity have resulted in the publication of vast amounts of erratic data, which have been difficult to apply even to the body of water upon which the determinations were made.

San Diego Bay, with a relatively small annual temperature variation, was known to have a prodigious biologic activity at all seasons of the year. The mean daily temperature of the bay rarely decreases below 15° C. and frequently rises above 20° C. The mean annual temperature is about 20° C. Phytoplankton blooms occur throughout the year, but with greater frequency during the warmer months than during the winter.

Effect of Blooms

The blooms, which are generally apparent by a change in the color of the water and decreased transparency, cause supersaturated dissolved oxygen concentrations in most parts of the bay. At such times, dissolved oxygen concentrations up to 200 per cent of saturation have been found and gross dissolved oxygen productions up to 8.00 p.p.m. in 24 hr. have been noted in samples of bay water incubated in the bay near the surface and exposed to daylight.

Data on dissolved oxygen in San Diego Bay were compiled from reports by a U. S. Navy Research Reserve Unit (16), by the California Department of Fish and Game (17), and by the Bureau of Sanitary Engineering, State Department of Public Health (18). Additional data on oxygen production and consumption were obtained by the staff of the San Diego Regional Water Pollution Control Board.

Peculiarly, the blooms have much less effect on Area C, previously described, than on Areas A and B. Oxygen production and consumption in most of Area C appear to remain at a fairly fixed level and low oxygen concentrations persist for longer periods. Area C is shallow and the currents created by the wind and tide produce high turbidities, mainly mineral in source. Apparently the amount of light available to the chlorophyll-bearing organisms is materially reduced.

Although the blooms produce tremendous amounts of oxygen, it is not this condition that is of interest from the standpoint of this report, but rather the period during which biological activity may be considered normal. During these periods, which range from a few days during the summer to several weeks in the winter, low oxygen concentrations are found in large areas of the bay. In some instances noticeably low concentrations have been found well up towards the mouth of the bay, where there is a huge ingress of oxygen-saturated ocean water on each flood tide. These low oxygen concentrations are the result of the demand placed on the bay by the fresh wastes discharged daily and the mean combined oxygen demand of the bay waters. The oxygen demand of the bay is discussed in another section.

From the results of an extensive series of samples taken and incubated in San Diego Bay under light and dark conditions—as shown, for example, in Table III and from the results of the survey conducted in 1951 (18)—values shown in Table IV were obtained. In reviewing these data, the reader is cautioned that the data in Table III have been included for illustrative purposes and do not represent critical or average conditions. Additional data covering the more critical periods of the year are being obtained. Based on scattered sampling during periods of minimum hours of daylight, it is believed that the summary values of minimum reliable oxygen production by the chlorophyll-bearing flora of San Diego Bay (Table IV) are high and that there may be

TABLE III.—Oxygen Production and Consumption in San Diego Bay (24-Hr. Incubation, No Bloom)

Zone	Location of Sample, Buoy No.	Depth[1] (ft.)	Sample[2]	D.O. (p.p.m.)	Change from Initial D.O.	Temp. (° C.)
A	A	Surface	I	7.60	—	17.5
			L	8.60	+1.00	
			D	7.20	−0.40	
		20	I	7.90	—	
			L	7.90	0	
			D	7.50	−0.40	
A	C1	Surface	I	6.20	—	19.0
			I	7.30	+1.10	
			D	5.75	−0.45	
		20	I[3]	6.00	—	
A	C15	Surface	I	5.00	—	19.8
			L	7.10	+2.10	
			D	4.50	−0.50	
		20	I	5.05	—	
			L	5.30	+0.25	
			D	4.65	−0.40	
AB	C16	Surface	I	5.20	—	19.6
			L	6.80	+1.60	
			D	4.60	−0.60	
		20	I	5.10	—	
			L	5.20	+0.10	
			D	4.70	−0.40	
AB	C17	Surface	I[3]	4.85	—	20
		20	I[3]	4.90	—	
B	M27	Surface	I[3]	4.60	—	20.2
		20	I[3]	4.70	—	
C	M92A	Surface	I	4.10	—	22.3
			L	5.50	+1.40	
			D	3.70	−0.40	
		20	I	3.70	—	
			L	3.40	−0.30	
			D	3.40	−0.30	
C	M99A	Surface	I	4.85	—	
			L	5.70	+0.85	
			D	4.50	−0.35	

[1] Surface depth = 0.5 to 1.0 meters below water surface.
[2] I = initial D.O.; L = 24-hr. light-incubated sample; D = 24-hr. dark-incubated sample.
[3] Incubated samples lost.

periods during the late fall and winter months when the oxygen produced by photosynthesis is considerably below that indicated. This would explain the low dissolved oxygen concentrations observed from time to time during those seasons of the year.

In arriving at the foregoing estimate, the compensation depth for the various sections of the bay was assumed as one-half the depth of that section. The compensation point is defined as that light intensity at which oxygen production and oxygen utilization are equal. The compensation depth is the depth at which the com-

pensation point occurs. The assumption is based on measurements of the transparency of the bay with a Secchi disk and on the results of many determinations such as those shown in Table III. The oxygen production in any section is then taken as one-fourth the mean surface production.

Higher oxygen production values were used for zone B because in all determinations, whether during periods of bloom or no-bloom, the oxygen produced was found to be greatest in the most polluted areas. However, the transparency of the water in the same areas generally was correspondingly lower.

Several other interesting observations may be made about biologic activity in such waters. It is possible for pollution to increase to the point that environmental conditions for the support of a beneficial plankton population may become unsatisfactory. Under these conditions, although blooms and high oxygen concentrations might still occur, generally, oxygen concentrations in the bay would fall below any acceptable level. The biologic oxygen is independent of the dissolved oxygen concentration and in sea water it is not limited by the supply of carbon dioxide.

Additional proof of the existence of turbulence was supplied by the vertical distribution of dissolved oxygen during blooms. At such times, when, due to diminished transparency, oxygen production was limited to within a few feet of the surface, supersaturated oxygen concentrations were found at all depths, with little difference between surface and bottom samples except in certain deep portions of the bay where a thermocline might develop.

Oxygen Supplied by Tidal Exchange

Superficially, the greatest source of oxygen available to San Diego Bay is that brought in with the saturated ocean waters on each tidal exchange. Actually, little of this oxygen is available for the stabilization of pollution in the central and south areas of the bay. If it were available, the existence of low oxygen concentrations throughout these areas would be virtually unknown. This is anything but the case, for, as previously described, San Diego Bay is approaching the permissible level of dissolved oxygen concentrations permitted by the objectives of the Regional Water Pollution Control Board.

For example, using a mean value of 8.0 p.p.m. for the dissolved oxygen concentration in the new sea water at each flood tide, a mean tidal range of 4.2 ft., and an area of 484,500,000 sq. ft., the gross oxygen brought into the bay on each flood tide is approximately 1,018,000 lb. Of this, only one-half is available, since the long-range objectives for San Diego Bay require a minimum dissolved oxygen concentration of 4.0 p.p.m., and with an average of 1.9 tides per day (tides in San Diego Bay are of the mixed type) the available oxygen presumably brought in per day would be 967,000 lb.

TABLE IV.—Reoxygenation by Chlorophyll-Bearing Flora, San Diego Bay

Zone	Area (sq. ft. $\times 10^6$)	Mean Depth (ft.)	Volume (cu. ft. $\times 10^6$)	Gross O_2 Prod. (p.p.m./day)		O_2 Avail. (lb./day)
				At Surface	In Zone	
A	144	37	5,330	1.00	0.25	83,300
B_1	76.5	32	2,450	1.50	0.38	58,100
B_2	102.5	12	1,230	1.00	0.25	19,400
C	161.5	7	1,130	1.00	0.25	17,700
Total	—	—	—	—	—	178,500

Ketchum's (19) approach to the exchange of waters in tidal estuaries was investigated to determine its usefulness for calculating the amount of new sea water distributed to Areas A, B, and C on each tidal exchange. The corollary determination of the "age" of the bay water in the various sections was also considered. Ketchum's method is most applicable to positive estuaries, in which the salinity of the estuary is somewhat less than that of sea water. This is not the case in San Diego Bay, except for a very short period during the rainy season. Based on some of the concepts developed by Ketchum, however, several simplifying assumptions were made which led to a logical solution of the problem in San Diego Bay.

The report of the U. S. Navy Volunteer Research Unit (16), although it furnished much important data, did not provide a solution to the problem of the distribution of new sea water in the bay. Basically, this report was an investigation of the flushing problem in San Diego Bay and the data were applied to determining the hydraulic rate of decay of radioactive contamination resulting from an underwater nuclear explosion in San Diego Bay. The flushing rate is based on a determination of the coefficient of eddy diffusivity for the estuary. Unfortunately, it has since been discovered that several simplifying assumptions are in error and this may cause the coefficient of eddy diffusivity to be off by several orders of magnitude.

The ratio of volumes of Sections A, B, and C of San Diego Bay at mean lower low water are 7.2:4.65:1, respectively. The total tidal prism represents 2.9 times the volume of Section C. Assuming that there is no stratification in the bay, which is essentially true, and that the tidal prism from each section is thoroughly mixed and distributed both on flood and ebb tides with the section downstream, the calculations become rather simple but tedious. It is emphasized that the assumption of complete mixing is probably far from true and to obtain a correct picture, the bay should be divided into several additional sections for which the assumption would be essentially right. However, the postulate presents the most favorable conditions that could exist. It appears obvious from the foregoing that ocean water coming into the estuary on a flood tide would not reach Areas B and C on that particular exchange, and upon calculation it is found that it requires three complete tidal cycles for water entering at Ballast Point to pass into Section C. It requires two complete tidal cyles for ocean water to reach Section B. At this time the ocean water entering as above represents only 50 per cent of the flood waters entering B, and less than 10 per cent of the water entering C. During the period the oxygen which was introduced is being rapidly depleted. The best determination of what actually is happening is apparent from a consideration of the dissolved oxygen concentrations found in the bay at all stages of the tide. From these data, it appeared that only 1.0 p.p.m. of oxygen was available in the water transferring from Section A to Section B. Also, water entering Section B from A at high tide had little effect upon the D.O.'s found in Section B. Based on this availability of oxygen and the passage of a mean tidal prism of 1,425,000,000 cu. ft. from Section A to B on each exchange or, using 1.9 tides per day (2,700,000,000 cu. ft. per day), there are 169,000 lb. of oxygen transmitted to Section B per day under present conditions. Should the bay be loaded so that the oxygen content of much of Area B would be 4.0 p.p.m., no beneficial oxygen would be available in Area B from A. Based on the estimate of only 10 per cent of the ocean water entering C three cycles later, and on present depleted oxygen concentrations in B and C, no oxygen is available to C from the tidal exchange. In other words, Section C

TABLE V.—Summary of Oxygen Resources of San Diego Bay

Oxygen Source	Oxygen (lb./day)			
	Zone A	Zone B	Zone C	Total
Atmospheric reaeration[1]	53,000	40,300	39,400	132,700
Biologic activity	83,300	77,500	17,700	178,500
Tidal exchange[2]	798,000	169,000	0	967,000
Total	934,300	286,800	57,100	1,278,200

[1] Assuming 4.0 p.p.m. D.O.
[2] Under present conditions.

must depend on atmospheric reaeration and planktonic activity for dissolved oxygen.

The data on the availability of dissolved oxygen in San Diego Bay are summarized in Table V. It might be argued that this approach is somewhat unrealistic and that the available oxygen for additional waste disposal should be based on the difference between what now exists in the bay and the permissible limit of 4.0 p.p.m. However, on September 23, 1950, and May 22 and 23, 1952, for example, analyses of D.O. in the central region showed mean values approaching 4.0 p.p.m., indicating no surplus of oxygen.

Oxygen Demand Loading

It has been common practice in studies of tidal estuaries to base the oxygen demand to be met entirely on the oxygen loading due to wastes. This approach generally leads to values for the ultimate capacity of the natural waters far in excess of what can be stabilized. It was estimated at one time that the wastes from a population of 60,000,000 could be discharged into New York Harbor without serious oxygen depletion. At the same time it was observed by others that serious oxygen depletion already existed with only a fraction of that population.

B.O.D.'s (24-hr.) obtained in San Diego Bay by incubating samples of the bay waters in the bay gave values that were above what might be expected for unpolluted waters in the general area. Samples of ocean water obtained and incubated at the end of the Scripps Institution of Oceanography dock approximately 12 mi. north of the entrance to San Diego Bay had a mean 24-hr. B.O.D. of 0.1 p.p.m. Samples taken and incubated in Mission Bay, a large recreational development approximately 4 mi. north of San Diego Bay and into which there is no waste disposal, were found to have a 24-hr. B.O.D. of 0.20 p.p.m. The waters in Mission Bay were found to be saturated or slightly supersaturated. Plankton blooms are rarely observed in Mission Bay. On the other hand, in San Diego Bay the mean 24-hr. B.O.D. in most sections of the bay was about 0.5 p.p.m. and in large areas of Section B, adjacent to which most of the wastes are disposed, demands several times this amount were found. During phytoplankton blooms 24-hr. oxygen demands up to 3.50 p.p.m. were found. Table VI shows the mean 24-hr. oxygen demands for San Diego Bay based on the experimental determination of 24-hr. B.O.D. in the bay. In addition, it is felt that a portion of the daily increment of waste discharged should be added as apart from the mean value of the bay water oxygen demand. The assumption is made that for the first 24 hr. the initial oxygen demand of the wastes discharged to the bay is exercised in addition to the average oxygen demand or, in other words, that it requires at least 24 hr. or approximately

TABLE VI.—Mean Oxygen Demand of San Diego Bay Waters

Zone	Mean Volume (cu. ft. $\times 10^6$)	Daily O_2 Demand	
		(p.p.m.)	(lb.)
A	5,330	0.4	133,000
B_1	2,450	0.75	115,000
B_2	1,230	0.5	38,800
C	1,130	0.5	35,400
Total	—	—	322,200

TABLE VII.—Principal Waste Discharges into San Diego Bay

Source of Discharge	Volume (m.g.d.)	B.O.D. Loading (lb./day)	Pop. Equiv.	Remarks
San Diego[2]	38	47,500	280,000	Primary effluent, unchlorinated
Chula Vista[2]	1.2	1,000	6,000	Intermediate effluent, chlorinated
Coronado	1.0	2,200	13,000	Raw sewage
Military installations[3]	2.0	3,300	20,000	Raw sewage
Misc. san. discharges[3]	0.3	500	3,000	Raw sewage
Fish canneries[3, 4]		3,760	22,500	Industrial waste[4]
Kelco Co.[3]	0.86	11,450	67,400	Industrial waste
American Proc. Co.[3]	1.65	1,670	10,000	Industrial waste
Total	45.01	71,380	421,900	

[1] Population equivalent based on 0.17 lb. 20° C. 5-day B.O.D. per capita per day.
[2] Municipal sewage treatment plant.
[3] Data from Reference (18).
[4] Based on average of 7.3 lb. 5-day B.O.D. per ton of tuna.
[5] Includes thawing of fish.

two tidal cycles for waste to be distributed so as to lose its identity.

From Table VII, the 20° C. 5-day B.O.D. of all wastes discharged to San Diego Bay is 71,380 lb. per day. Since the 1-day B.O.D. is assumed at 30 per cent of the 5-day value at 20° C., the resulting oxygen demand increment is 21,400 lb. per day. Of this, approximately 800 lb. per day is in Area A, 20,300 lb. per day in Area B, and 300 lb. per day in Area C.

A comparison of Tables V and VIII shows that in Area A a large surplus of dissolved oxygen is available for the disposal of wastes, provided the waste discharge is located sufficiently close to the mouth of the bay to take advantage of the maximum flushing and availability of oxygen in new ocean water.

In Section B the present oxygen demand is estimated at 174,100 lb. per day and the ultimate oxygen resources, excluding the oxygen brought in by tidal exchange, are 117,800 lb. per day. Including tidal exchange based on the availability of 1.0 p.p.m. oxygen in that portion of the tidal prism which must pass from A to B, the oxygen resources of B are estimated at 286,800 lb. per day. This presumably leaves a surplus for Section B of 112,700 lb. per day. Actually, the assumption that the tidal prism is thoroughly distributed throughout the section is somewhat idealistic and at best little effect has been found experimentally on Zone B during the tidal cycle. Based on the foregoing considerations, it appears that under normal conditions in San Diego Bay the central portion of the harbor has reached the limit for the disposal of wastes imposing oxygen demand loadings.

Much of the principal oxygen demand waste discharges are in proximity to Section C. The volume of the mean tidal prism is approximately equal to the volume of Area C and it becomes obvious that there is probably an oxygen deficit below 4.0 p.p.m., the objectives of the Regional Water Pol-

TABLE VIII.—Summary of Existing Oxygen Demand in San Diego Bay

Zone	B.O.D. (lb./day)		
	In Bay Waters	By Wastes	Total
A	133,000	800	133,800
B	153,800	20,300	174,100
C	35,400	300	35,700
Total	322,200	21,400	343,600

lution Control Board, in the portion of the tidal prism which moves from B to C. The calculated oxygen resources of Area C are 57,100 lb. per day and the oxygen demand is 35,700 lb. per day. The ability of Area C to absorb additional wastes is extremely limited.

It is very difficult to anticipate the changes which might take place in the bay in the case of continued growth of the region as in the past. Much work remains to be done in placing calculations such as those attempted here on a completely justifiable basis. It is possible that relatively small increases in oxygen demand loadings may so increase the basic oxygen demand of the estuary water as to cause definitely unsatisfactory conditions. Increased waste loadings may cause a decrease in the oxygen-producing activity of the biologic life, thus resulting in decreased availability of dissolved oxygen. Also, the effect of surface active substances present in the wastes on atmospheric reaeration has never been fully evaluated in natural waters except to indicate that they interfere with the transfer of oxygen.

Little is known about the dynamics and flushing of neutral estuaries such as San Diego Bay. A final conclusion that might be drawn from this study is that estuaries such as San Diego Bay have a limited capacity for the disposal of wastes not predictable on a basis of size or volume of water circulated and that large waste discharges must either be treated to produce an effluent of high quality or be entirely removed therefrom.

Acknowledgments

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WILLEM RUDOLFS RETIRES

Retiring as Chairman, Department of Sanitation, New Jersey Agricultural Experiment Station, Dr. Willem Rudolfs, world-renowned authority on sanitation and industrial wastes problems, leaves behind him a 33-year record of impressive accomplishment at Rutgers University. Although his retirement officially begins on January 1, 1953, he left for Holland, where he plans to make his permanent home, on November 8, 1952.

No definite future plans have been formed by Dr. Rudolfs. He has indicated, however, that he plans to travel a good deal abroad with Mrs. Rudolfs, perhaps doing some consulting and reference work. He expresses particular interest in current European sanitary engineering developments, but plans to return to the United States from time to time and to contribute to the Journal as both an author and an abstractor.

THE OPERATOR'S CORNER

CONDUCTED BY HERBERT P. ORLAND

OPERATOR RESPONSIBILITY FOR PUBLICATION

Practical improvements in wastes treatment plant operational methods must, of necessity, come from the grass-roots experts—the operators. In no other way than by day-to-day living with a plant and its problems can the same fundamental knowledge be gained.

In solving their problems, operators depend in large measure on interchange of information with their colleagues. It is unfortunate indeed that most of the valuable suggestions and experience reports thus given verbally are lost forever to those who may be seeking solutions to the very same problems, simply because they have not been written down or made available through publication.

This is the motivation behind the plea made by John T. Tapleshay in his paper, published elsewhere in this Corner, when he says:

"More plant operators should contribute to the publication of operation methods. Analysis of most of the published papers shows them to be either in the realm of pure research or related to correction of troubles. Yet by far the majority of plants are operated trouble-free, although from personal contact it is known that many of the operators of these plants have employed methods which are not generally known. Dissemination of these ideas would aid all."

Dissemination of operational helps is the very purpose of The Corner. On the operators themselves, however, falls the duty of furnishing the material to be disseminated. The Corner is simply a forum-in-print, acting as a discussion leader and recording contemporary advances in the art of sewage and waste treatment for use by others.

But those who read, and never write, would do well to reflect on the thought that if everyone took that attitude there would be nothing to read, particularly in such a medium of exchange for operational matters as is The Corner. Like a market place, it cannot operate if merchandise is always removed and none is brought in.

Look around; dig into those diaries, those reports, and the storage spaces of memory. Many of the kind of items we are seeking and you like to read are lying half-buried there. Pass them along, if only in a letter, some clippings, or even a marked operating report. And don't take the "I-can't-write" attitude: you'll never know whether you can write or not unless you try. Besides, writing is our job, and we're here to help you help others. Pass the ammunition; we're ready, willing, and able to fire it where it will do the most good. H. P. O.

OPERATION OBJECTIVES IN THE ACTIVATED SLUDGE PROCESS *

By John T. Tapleshay

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Since the activated sludge process was first recognized, almost 40 years ago, it has had the most rapid and phenomenal growth of any of the many types of sewage treatment. Today the process is used in plants the world over, with scores of new plants being started each year. In the United States alone, the activated sludge process treats the sanitary wastes of more than 25,000,000 people in plants having a design capacity in excess of 2,500 m.g.d.

From the inception of the process it has attracted widespread interest, resulting in the greatest concentration of research any sewage treatment process has ever enjoyed. The results of this research have been exemplified in many ways. The basic principles of the process have become well established, while operation procedures and design features have, in general, become standardized.

Research in great volume, still being carried on in many phases of the activated sludge process, will undoubtedly result in still greater advances. The basic value of research and the numerous publications cannot be questioned; yet in some ways the enormous wealth of published material has worked to the disadvantage of the process. To many lay people, and even to some engineers, the existence of so much technical literature has caused them to consider the process a highly complicated one requiring a superman to operate it. This idea is easily refuted when one considers the great number of plants successfully operated by men who have had little or no formal technical training. Such men have been able to obtain the necessary technical training through operator training services as provided by manufacturers of process equipment and through short courses as sponsored by many of the State Boards of Health in cooperation with the state universities.

Present day concept of the process has undergone some changes as operation control methods have become established. It has come to be realized that activated sludge is not as temperamental as once was believed. The process has been shown capable of handling loads far greater than once thought possible. This has been clearly shown, for instance, by the successful design and operation of plants treating milk wastes.

Several Modified Forms

At the 1951 Annual Meeting of the Central States Sewage and Industrial Wastes Association, Mohlman (1) reviewed the progress made in the activated sludge process in the last 25 years. One of the essential points brought out was the present tendency of sanitary engineers and others in the field to label all forms of treatment using aeration, with return sludge, as activated sludge. He contends that this is erroneous. In the last few years there has been a marked movement toward design of intermediate degrees of treatment utilizing various forms of the aeration process. These plants have variously been called high-rate activated sludge, modified activated sludge, and short-period activated sludge; but in all cases the label of activated sludge has been given them. Fundamentally, no fault can be found with the label, as they all employ the biological process associated with the true activated

* Presented at 1952 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; August 27–29, 1952.

sludge plant. There is, however, a great variation in the degree of treatment obtained by the various forms.

In the past 25 years, activated sludge, as a type of biological sewage treatment, has gained a reputation, and rightly so, of being a method capable of producing an effluent of the highest quality possible. Any attempt to similarly label all modified forms of the process will inevitably result in a lessening of the present reputation of the true process. Experience has shown that the modified forms soon lose their qualified name and are referred to by many as activated sludge plants, the result being that many people have developed an erroneous impression of the process as a whole.

The author has no fault to find with the modified forms. On the contrary, it appears that the greatest progress in the biological process of treatment will take place in such developments. However, it is believed that such modifications of true activated sludge should be labeled in such a manner that no mistake can be made as to the degree of treatment they will produce and so that they are not confused with standard activated sludge.

The fundamental objective in the operation of an activated sludge plant is the same as in any other type of plant —namely, to obtain the best possible effluent that the plant is capable of producing. To accomplish this result there are several supplemental objectives which must be borne in mind by the operator. These are as follows:

1. Know your own plant, its limitations and capabilities.
2. Know the characteristics of the sewage and the flow.
3. Familiarize yourself with basic comparative data from similar plants to guide you.
4. Maintain proper operation procedures.

A discussion of each of these objectives follows.

Plant Design and Capabilities

Almost invariably, in any discussion of plant design, the capacity of a plant is given in terms of flow. The engineer has, of course, designed for a particular strength sewage and a specific loading in pounds of B.O.D. Too often, however, the plant operator either is not thoroughly familiar with the design or does not realize the full import of it. It is of utmost importance that the operator realize the significance of plant loading, since his plant can be below design in hydraulic flow and yet be considerably overloaded organically if the strength of the sewage is higher than that assumed in the design.

It is of equal importance that the operator be thoroughly familiar with the structural features of his plant, especially those features which may lead to trouble. Such fundamental data as detention times, overflow rates in settling tanks, pump capacities, and air capacities are usually well-known. Frequently, however, supposedly inconsequential details, such as method of flow distribution to tanks, poor hopper slopes, and dead channels, are neglected. The fact that faults in design may exist is not nearly so serious as the operator's lack of knowledge of their existence, because he then does nothing to correct for them.

Frequently, efficient operation of a plant will result in its being able to handle considerably higher loadings than those designed for. If at all possible, experimentation in plant operation should be practiced in order to determine the actual limits in plant capacity, as design figures, of necessity, cannot always be absolutely accurate.

Characteristics of Sewage and Flow

One of the frequently heard comments in the sewage field is: "Sewage is different wherever you go and no two cities are alike." This, to a degree, is correct; yet, fundamentally the difference is not as great as generally supposed. If it were, how could the coun-

try-wide success of a single process of treatment such as the activated sludge process possibly be accounted for? The differences are not so much in characteristics as in degree. One characteristic which is extremely variable, however, is that of flow.

In small cities up to 50,000 population the fluctuation in flow is usually very marked, with peak rates three to four times the average rates. This can cause trouble, due to hydraulic and/or organic overloading, especially if the peak rates last over most of the day. Under these conditions the period of low flow may not be long enough to offset the period of high flow, even though the average flow may be lower than the design average. In such cases it is imperative that the operator regulate control factors based upon peak rates rather than average rates. He must also be fully aware of the effect of such peak rates upon the design factors of detention time, aeration capacity, and air volume.

Sufficient analytical data should be obtained to determine peak loadings in B.O.D. at times of peak flows. These data must supplement those obtained for average conditions so that proper control can be exercised.

Basic Comparative Data

The importance of knowing design and operating characteristics of one's own particular plant cannot be overemphasized. It is only by knowing such characteristics that intelligent comparison with other plants of similar type can be made. Very often certain operating procedures which prove successful at one plant seem entirely unsuccessful at another. In almost all such cases the reason for the failure is due to the fact that basic factors are ignored. The procedures may be tried in the exact manner as used elsewhere, with no correction or adaptation for the conditions existing at the second plant. Obviously, the likelihood of success in utilizing the procedures in such cases is slim.

Comparative data from other plants can be of infinite help in operation of a plant, but such data should be in basic form. Such data as the weight of suspended solids in the mixed liquor, the rate of return sludge, the volume of air to supply, and the aeration detention time cannot be used for comparative purposes without putting them in unit forms. Mixed liquor solids must be related to the strength of the sewage and the available aeration period. Air supply must be considered in terms of pounds of B.O.D. removed by the secondary process and/or the volume of aeration capacity. Return sludge rate must be related to settling characteristics of the sludge and the dissolved oxygen level in the final settling tanks.

Every operator should take advantage of the excellent interchange of ideas and data which exists in the sewage field. It is doubtful if any other field has a more closely knit and cooperative organization than is open to him.

Maintenance of Proper Operation Procedures

The foregoing objectives are necessary in order that proper operation procedures can be determined. The most important objective in plant operation, however, is the maintenance of proper procedures once they are determined. The old adage that "an ounce of prevention is worth a pound of cure" is particularly applicable to operation of an activated sludge plant. With proper operation, the advent of abnormal conditions almost always can be anticipated so that corrective measures can be instituted. By immediate correction of any abnormal condition, serious trouble can be avoided.

The primary source of information indicating trouble is the plant records. It is of little use, however, to try to determine causes of trouble from records

unless they are good and represent actual conditions. Operational procedures should, therefore, be reviewed to determine the following points:

1. Are samples representative of actual flow conditions? Are they taken at a time of day which will be of most value? Are they composited according to flow?
2. Is sludge withdrawal from the primary tank proper? Is waste sludge rate controlled adequately?
3. Are aeration tanks operated properly? Is the air supply varied in accordance with the load? Is the mixed liquor concentration proper for the type of plant and load? Is the D.O. level adequate?
4. Are the final tanks operated properly? Is the return sludge rate proper for conditions? Is the D.O. level adequate?
5. Are the digesters operated properly? Is supernatant returned slowly or all in one slug?

If all the above points are found to be correct when compared to normal operating figures, no difficulty will be encountered. When, however, one or more vary from the normal, corrective measures must be started, and started immediately.

In some instances, all operational and physical factors may be proper, but the plant may be overloaded and, therefore, not producing a proper effluent. In such cases there is little that can be done but enlarge the plant. Frequently, however, a better over-all effluent will be obtained if a portion of the flow is given primary treatment only, the remainder is given secondary treatment, and the two portions are then mixed.

In other cases, where none of the design limits have been exceeded but the sludge has bulked due to a temporary lapse in control, the sludge can be brought back into shape by chlorinating the return sludge. The chlorine will improve the settling characteristics of the sludge almost immediately and within three or four days normal conditions will be re-established.

One other operational problem which has developed in recent years is that of frothing in aeration tanks. The one positive cure for this is maintenance of high solids (2,500 to 3,000 p.p.m.) in the mixed liquor. If the air supply is inadequate to maintain solids this high, a spray system can be installed or defoaming agents can be added.

It is apparent that no positive cure-alls have been given for troubles which may be encountered. Rather it has been the intention to point out that the surest way to avoid trouble is to recognize its symptoms. This can best be done by knowing the individual plant, applying procedures based upon conditions at that plant, and instituting corrective measures as soon as abnormal conditions show up.

There is one last comment, which also might well be termed an important objective. More plant operators should contribute to the publication of operation methods. Analysis of most of the published papers shows them to be either in the realm of pure research or related to correction of troubles. Yet by far the majority of plants are operated trouble-free, although from personal contact it is known that many of the operators of these plants have employed methods which are not generally known. Dissemination of these ideas would aid all.

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ACTIVATED SLUDGE PLANT OPERATION *

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Nature of Activated Sludge

The impurities in sewage are present in three forms: suspended, colloidal, and dissolved. Only the heavier suspended matter can be removed by plain sedimentation. The cloudiness of sewage is due to the colloids and finely divided suspensoids. When settled sewage is aerated for protracted periods, those particles will coalesce to form light feathery floc, which settles slowly upon quiescent standing. The supernatant liquor will be relatively clear. If that liquor is discarded and the thin sludge is reaerated in a second batch of settled sewage, a shorter period will suffice to produce clarification and more sludge will result. If this cycle is repeated several times, it will be found, at first, that as the amount of sludge increases, the clarification time decreases, but eventually a point will be reached beyond which further increments of sludge are of little or no value in reducing clarification time. At that point clarification may occur in 10 to 30 min.

During the process of flocculation and clarification many of the bacteria and protozoa in the sewage are adsorbed on or enmeshed in the floc. In the presence of abundant dissolved oxygen some forms die off, or remain dormant, while others multiply rapidly. By the action of their growth these organisms convert the pollutants adsorbed on the sludge or dissolved in the sewage to carbon dioxide, sulfates, nitrates, and the living protoplasm of their own bodies. This process is termed biological oxidation. During its progress bacterial enzymes are secreted which hasten clarification.

It is important to remember that flocculation, clarification, and oxidation, as encountered in the activated sludge process, are dependent upon biological activity, which in turn is dependent upon oxygen. Without that biological activity flocculation would be slower, clarification would be less complete, and oxidation might not occur at all.

Both oxidation and clarification take place most rapidly when the sludge and sewage are first brought together, providing there is sufficient oxygen available. But, unlike clarification, oxidation cannot be completed in a few minutes—several hours, or even days, are required for that. Unless sufficient time is allowed between cycles for oxidation to catch up with adsorption, the settleability of the sludge deteriorates and, if oxidation continues to lag, the clarifying power of the sludge is also reduced.

Classification of Activated Sludge Processes

There are several different modes of operation or degrees of treatment that conform to the accepted definition (1) of the activated sludge process.

In the early days all activated sludge plants were expected to produce a clear, highly nitrified effluent containing less than 10, and frequently less than 5, p.p.m. of 5-day B.O.D. or suspended solids. In such a plant a nonnitrifying sludge was obviously unsatisfactory. Later many authorities concluded that nitrification was unnecessary. It was found that at most plants considerable reduction in air, and hence power consumption, could be made if nitrification was avoided. The effluents from these plants still had about the same suspended solids and B.O.D. as those from the nitrifying

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process. Both of these processes are termed "conventional" process and both yield about 90 per cent reductions in applied B.O.D. when treating a pre-settled typical municipal sewage.

A later development has been the so-called high-rate activated sludge process, which does not attempt to produce a high quality effluent. When treating a typical municipal sewage it yields an over-all B.O.D. reduction of about 75 per cent, which is equivalent to about 60 per cent on the basis of settled sewage.

Still farther down the ladder of B.O.D. removal, are straight aeration plants with relatively long aeration periods. Although these plants return no sludge to the aerators, their aeration periods are so long that the floc formed in the aerators may have appreciable biological activity. These plants may yield over-all B.O.D. reductions of 60 per cent, or about 40 per cent on the basis of the applied settled sewage (2)(3).

Recently the so-called "Biosorption Process" has been announced. Like some of the earlier activated sludge plants, this process omits any primary treatment other than screening and grit removal. According to the flow sheet for this process, equal volumes of normal crude sewage and activated sludge are intimately mixed for 35 min., after which the mixed liquor enters a conventional settling basin. Settled effluent is discharged to the stream. Sludge withdrawn from the settling tanks is passed through a "sludge stabilizer" or "aerobic digester" having a 2½-hr. aeration period before it is again mixed with crude sewage. The "sludge stabilization" or "aerobic digestion" is simply sludge reaeration under a new name. Sludge reaeration has been used in either nitrifying or non-nitrifying conventional plants and also in some high-rate plants. In the author's opinion, the newest things about the Biosorption Process are the names used and the short contact period between sludge and sewage.

Regardless of the particular type of activated sludge process under consideration, much the same control tests are used. However, their significance and the interpretation of their results may differ, depending upon the degree of treatment being sought. The various control tests most commonly used are (a) those to regulate aeration, (b) those to control the amount of sludge, and (c) those to measure the condition of the sludge.

Dissolved Oxygen Tests

Dissolved oxygen tests are by far the best and perhaps the only logical method of controlling aeration. In any aeration tank there are two opposing forces—the aerator device injecting air (oxygen) into the sewage-sludge mixture, and the biological organisms using oxygen in their life processes. So long as the first force exceeds the second, there will be some dissolved oxygen in the mixed liquor and so the operator can be reasonably certain that aeration is adequate. If there is no dissolved oxygen present then the reverse is true, no matter how much air is being applied.

The oxygen requirements depend primarily upon the amount and condition of the sludge present, and are always greatest at the point where the sludge and sewage first come in contact with one another. When considerable sludge is being carried, the variations in volume and strength of the sewage have little, if any, influence on the air requirements and so aeration may continue at a practically constant rate. When lesser amounts of sludge are carried, there will be some hourly variation in oxygen requirements. Under those conditions, and in larger plants, the saving in power resulting from intelligent variation in air supply may be sufficient to warrant making dissolved oxygen determinations several times a day. However, in small plants, or those carrying a high concentration of sludge, one set of determinations

per day, preferably about 6 hr. after the peak sewage load reached the aerators, should suffice.

The dissolved oxygen determinations should be made at various points from inlet to outlet of the aerators. At least in conventional plants, it is desirable to always have at least a trace of oxygen at the inlet end and gradually increasing amounts at succeeding points along the aerator. If a highly nitrified effluent is desired, it may be desirable to maintain as much as 3 to 6 p.p.m. of oxygen at the aerator outlets, but where nitrification is not desired 1 or 2 p.p.m. is probably adequate.

Because oxygen requirements are greatest when sewage and sludge first come together, it is frequently necessary to apply more air at the inlet ends of the aerators and gradually decrease aeration toward their outlets. This is termed "tapered aeration." Another solution to the problem is "step aeration," where either or both the return sludge and the sewage are introduced at several different points along the aerators (4) (5). Most plants have not been designed to permit use of step aeration.

Where sludge reaeration tanks are used, the air supply to them should be so adjusted as to maintain about the same dissolved oxygen as recommended for conventional mixed liquor aerators. One reason sludge reaeration tanks have come into ill repute is the fact that the solids concentration in them, and hence their oxygen requirements, are so high that it is virtually impossible to maintain any dissolved oxygen in them. Under such conditions retention of sludge in those tanks did more harm than good.

Retention of sludge in the bottom of final sedimentation basins is even more harmful. Some operators make routine measurements of sludge depths in final tanks and vary the rate of sludge withdrawal so that those depths never exceed 2 ft. Even lesser depths may be desirable.

By using sludge return rates as high as 50 per cent, or even 100 per cent, it is possible not only to avoid sludge build-up in final tanks, but also to dilute the sewage-sludge mixture at the aerator inlets (or the sludge in reaeration tanks) so that oxygen requirements will not be so great at those points. This is an alternative to either tapered or step aeration that is particularly applicable to small plants.

Amount of Sludge

The amount of sludge present in the mixed liquor is most accurately measured gravimetrically by making suspended solids determinations. Originally it was usually measured volumetrically by observing the percentage of sludge in a graduate of mixed liquor after a definite standing time. The objection to this method of measurement is that the volumetric reading is affected almost as much by settling characteristics of the floc as it is by their weight. If both methods of measurement are used, it is possible to calculate the "sludge index," which is a useful indicator of sludge condition.

Centrifuging is a third method of sludge measurement. It is more rapid than the other methods, but less accurate than the suspended solids test. All three methods are more fully discussed elsewhere (6).

The proper amount of sludge to carry depends upon the degree of treatment desired and the capacity of the aeration equipment. Generally speaking, diffused air plants can carry more sludge than those depending upon mechanical aerators. Typical mixed liquor solids concentrations for normal sewage are probably about as follows:

Conventional nitrifying plants, 3,000 p.p.m. or more.

Conventional non-nitrifying diffused air plants, 1,000 to 2,500 p.p.m.

Conventional non-nitrifying mechanical aeration plants, 600 to 1,500 p.p.m.

High-rate plants, never over 600 to 800 p.p.m., and frequently as little as 200 to 300 p.p.m.

Straight aeration plants usually have a higher solids concentration in the mixed liquor than in the settled sewage, despite the fact that they have no sludge return; perhaps 100 p.p.m. would be typical.

At present, frothing in aerators is generally attributed to detergents in the sewage. However, low solids concentrations at least aggravate the problem. The author encountered foaming at Salinas, Calif., whenever the solids were low, back in 1930 before the use of detergents was common.

Measures of Sludge Condition

Sludge Index

By far the most common measure of sludge condition is the sludge index, which is the ratio of the percentage of sludge by volume after standing 30 min. to the percentage of sludge by weight as measured by the suspended solids determination. It is a measure of the settling characteristics of the sludge; a high index indicates poor settleability, and *vice versa*.

A bulked sludge is simply a sludge that, after a given settling period, occupies a greater volume than would a normal sludge containing the same weight of suspended solids. Bulking is best measured by the sludge index. Whether or not a bulked sludge will pour over the weirs of final settling tanks depends upon the design of those tanks and the amount of sludge being carried. The more generous the design of the tanks, the higher the sludge index that can be tolerated in a given mixed liquor solids concentration (or, for a given index, the higher may be the solids concentration) before the tank effluent becomes fouled with sludge.

In conventional plants, either nitrifying or non-nitrifying, the primary cause of bulking is the failure of biological oxidation to keep pace with adsorption. The reason for that lag may be too short an aeration period, inadequate air supply, increased pollution load on the plant, insufficient sludge, septic sewage or return sludge, germicidal waste, excessive oil and grease, etc. Unless the cause is found and corrected, the sludge index increases, bulking occurs and, if it continues, the final effluent will eventually become fouled with sludge. In that event, the operator must reduce the amount of sludge he is carrying, even though the initial cause of the lag in oxidation may have been insufficient sludge. The net result of operation with a reduced amount of sludge will be a lower degree of treatment than had been hoped for.

High-rate activated sludge plants generally have a higher sludge index than do the conventional plants. However, when oxidation lags sufficiently behind adsorption for a considerable period of time, clarification itself is reduced. In such cases, the sludge index is lower than it is when there is less lag. Since such is the case, an increase in sludge index at a high-rate activated sludge plant may indicate the need for reducing, rather than increasing, the aeration period or the air consumption.

A slight excess of oxidation over adsorption favors nitrification and results in a low sludge index. However, too great an excess produces a dense "pinpoint" sludge that does not yield as clear an effluent as does the more flocculent sludge with a higher index. This may be another objection to sludge reaeration in conventional non-nitrifying plants. However, it is believed that in any properly designed and operated conventional plant sludge reaeration can be used to advantage.

Sludge Age

A less common measure of sludge condition is sludge age. As usually calculated, the sludge age is the ratio

of the total weight af activated sludge solids in the plant to the weight of suspended solids removed from the daily flow of settled sewage. Theoretically, at least, it might be more accurate to use the weight of total rather than suspended solids removed from the settled sewage. There may be other objections to the term, also. However, it has proved a useful tool in controlling some plants. Generally speaking, the older the sludge, the lower will be its sludge index and the higher will be its ash content. Only old sludges can be nitrifying sludges, because nitrification does not take place until after much of the carbonaceous material has been oxidized.

Volatile and Ash Content

The routine determination of ash or volatile matter in the return sludge is also a useful indicator of when to expect a change in sludge index. There does not seem to be any universal optimum volatile content for all plants. But, in most conventional plants, a rise in volatile content of the return sludge precedes a rise in sludge index and *vice versa*. Apparently this relationship does not necessarily hold for high-rate and/or straight aeration plants.

Microscopic Examination

Microscopic examinations of sludge are of value in conventional plants—particularly observations of the number and type of protozoa. Unless there is a preponderance of the larger ciliate protozoa over the smaller flagellates the operator can be certain that oxidation is lagging behind adsorption.

Miscellaneous

Other tests that are sometimes used to measure the condition of the sludge include measurements of its short-time oxygen requirements, comparisons between the dissolved solids concentrations in the settled sewage and in the plant effluent, grease determinations, etc. Oxidation potential may also be a useful tool, not only to measure sludge condition, but also to control aeration.

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INTERESTING EXTRACTS FROM OPERATION REPORTS

Attention operators! It will be appreciated if copies of all annual reports of both large and small plants are sent to the Federation office for abstracting in this section of the Journal. Carbon copies of typewritten reports will be promptly returned on request. Please direct annual reports to: Federation of Sewage and Industrial Wastes Associations, Room 325, Illinois Bldg., Champaign, Ill.

Fourteenth Annual Report of the Racine, Wis., Sewage Disposal Plant for 1951 *

By Thomas T. Hay, *Superintendent*

The average daily flow was 21.285 m.g.d., or 177 per cent of the designed capacity. Careful control and alert operation of the treatment facilities have kept the detrimental effects of this overload at a minimum. Part of the increased flow is due to increased population, but part also is due to the increased flow per capita, which was 292 g.p.c.d., or 7 g.p.c.d. more than in 1951.

Conversely, the strength of the raw sewage, as measured by suspended solids, has decreased for the last three years, in 1951 amounting to 157 p.p.m. as compared with 163 p.p.m. in 1950. The total dry suspended solids in 1951 amounted to 5,073.1 tons, as compared with 5,179.4 tons for 1950.

The strength of the raw sewage, as measured by B.O.D., also dropped during the year, amounting to 134 p.p.m., as compared with 145 p.p.m. in 1950. Total B.O.D. also decreased, being 4,344.5 tons as compared with the 1950 total of 4,579.2 tons.

Chlorine

The amount of chlorine used in 1951 was 68,300 lb., compared with 82,385 lb. in 1950 and 68,360 lb. in 1939. The chlorine demand of the raw sewage was 3.28 p.p.m. in 1951, compared with 4.3 p.p.m. in 1950 and 7.9 p.p.m. in 1939. The chlorine equipment was inadequate to meet the peak demand; therefore, a study of the chlorine needs was made in the early part of the year. As a result, the 750-lb. machine was replaced by two machines, one of 400-lb. and one of 1,000-lb. per day capacity. Another scale also was added.

Plant Efficiencies

The reduction of suspended solids in 1951 was 47 per cent, with 85 p.p.m. in the effluent. These values compare with 1950 values of 50 per cent and 81 p.p.m., and 1939 values of 75 per cent and 57 p.p.m., respectively. Average retention in the clarifiers was 1.65 hr. in 1951, 1.7 hr. in 1950. The design retention time is 3 hr.

B.O.D. reduction in 1951 was 38 per cent, with 83 p.p.m. in the effluent. These values compare with 1950 values of 39 per cent and 87 p.p.m., and 1939 values of 32 per cent and 123 p.p.m., respectively. Maintaining of these efficiencies with a loading 77 per cent in excess of the designed capacity is a compliment to the alert attention and careful control of the operating personnel and the constant interest of the entire staff.

Sludge

The amount of dry solids introduced into the digesters was 123 per cent of the 1950 amount. Comparison showed that the average digester loading of a number of plants was 0.059 lb. per cubic foot per day, so the loading on the

* For last previous extract see This Journal, **22**, 2, 255 (Feb., 1950).

digesters was 236 per cent of the average. In addition to this high loading, some raw sludge was highly chlorinated and wasted; some sludge was removed from the digesters before digestion was completed.

Gas produced in 1951 amounted to 94 and 169 per cent of that produced in 1950 and 1939, respectively. Although more volatile matter was added than in 1950, less gas was produced and only 54 per cent as much gas per pound of volatile matter. In addition to incomplete digestion due to overloaded conditions, the heavier sludge in the digesters kept sludge temperatures lower by interfering with the heat transfer.

At local space heating rates the value of the gas produced was $12,225.12; 70 per cent was used at the plant, the remainder being wasted.

Operating Costs

Labor and materials costs again increased. The same amount of labor as in 1950 cost $3,460 more. In spite of increased costs, however, $620 less was spent for materials. The operating budget was 104 per cent of the previous year.

Unusual Operating Conditions

The temporary bar screen, first used in 1948, was again used in the spring months. This again gave good protection and showed the need for a permanent bar screen installation. Under the overloaded conditions the treatment units are taxed to their limit. Any shock load or material not amenable to treatment throws the treatment out of balance. Under normal conditions many of these shock loads would be handled with little or no effect on the treatment process.

Sludge in digester No. 1 became so heavy that the mechanism was stopped and could not be restarted until the digester was emptied. Digesters No. 2 and 3 are approaching the same condition and probably will have to be emptied soon.

TABLE I.—Summary of 1951 Operation Data at the Racine, Wis., Sewage Treatment Plant

Item	Average
Total rainfall (in.)	28.61
Sewage flow (m.g.d.)	21.285
Per cap. sewage flow (gal.)	292
Settling tank retention (hr.)	1.65
Total solids:	
Influent (p.p.m.)	589
Effluent (p.p.m.)	485
Per cent reduction	17
Settleable solids:	
Influent (ml. per liter)	2.73
Effluent (ml. per liter)	0.12
Per cent reduction	96
pH:	
Influent	7.56
Effluent	7.51
Suspended solids:	
Influent (p.p.m.)	157
Effluent (p.p.m.)	85
Per cent reduction	47
B.O.D., 5-day:	
Influent (p.p.m.)	134
Effluent (p.p.m.)	83
Per cent reduction	38
Chlorine demand:	
Raw (p.p.m.)	3.28
Effluent (p.p.m.)	3.59
Raw sludge to digesters:	
Gal. per day	25,776
Per cent dry solids	8.09
Pounds dry solids	17,714
Per cent volatile solids	57
pH	6.66
Digested sludge:	
Digested solids to beds (lb./day)	2,726
Per cent solids	16.48
Per cent volatile solids	40
pH	6.79
Per cent solids in supernatant	0.81
Analysis of dry sludge (%):	
NH_3	2.45
P_2O_5	2.32
K_2O	0.46
Grease	3.96
Humus	39
Moisture	40
Gas, cu. ft. per capita per day	0.727
Gas analysis:	
B.t.u.	656
Oxygen (per cent)	1.2
Nitrogen (per cent)	1.5
Hydrogen (per cent)	1.4
CO_2 (per cent)	31
CH_4 (per cent)	64.9
Operating costs ($):	
Total	$84,796.13
Per capita	1.16
Per m.g.	10.97

The insulation on the new roof and the heating system in the clarifier room have demonstrated their worth. It has been possible to paint in this room all but a few days. Spalling of the brick is almost eliminated and will be entirely eliminated when the current painting program is completed. Deterioration of the steel work has been reduced to less than 15 per cent of the previous rate. As one complete painting of the clarifier room cost $15,150, the heating system placed in this room at a cost of $9,500 has already saved the city several thousand dollars.

Plant Unit Study

A complete analysis of each unit was made during 1951 to compare the unit with the standards adopted by the State Boards of Health of 10 states in the Upper Mississippi and Great Lakes areas. [The analysis for each unit, as given in the report, was used as the basis for detailed recommendations as to improvements, replacements, and additions in connection with plant needs. —Ed.]

Table I is a summary of the 1951 operating data.

Annual Report of the Sewage Disposal Commission of the City of New Britain, Conn., for Year Ended March 31, 1952 *

By John R. Szymanski, *Superintendent*

The plant safety program (see This Journal, 23, 10, 1334; Oct., 1951) continued in full operation and remains under close scrutiny. The number of small hazards discovered by the revolving Safety Committee is amazing, but

* For last previous extract see This Journal, **22**, 11, 1489 (Nov., 1950).

TABLE II.—Summary of 1951–52 Operating Data, New Britain, Conn.

Item	Average	Item	Average
Population served, equivalent	80,000	Hours run monthly	289.1
Sewage flow (m.g.d.)	12.45	Lb. wet filter cake produced, total for yr.	13,453,636
Daily max. (m.g.d.)	15.4	Lb. dry solids in cake, total for yr.	4,217,657
Daily min. (m.g.d.)	9.2	Rate (lb. per sq. ft. per hr.)	6.08
Screenings removed (cu. ft. per mo.)	2,249	Ash produced from sludge burning, total (cu. ft.)	34,651
Grit removed (cu. yd. for year)	175	Fuel oil used for heating and sludge incineration, total (gal.)	67,043
Grease skimmings removed (cu. ft. per mo.)	931	Suspended solids (p.p.m.):	
Chemical dosing:		Raw	198
Lb. copperas per mo. (when used)	37,017	Primary influent	233
Lb. chlorine per mo.	5,409	Primary effluent	154
Lb. Ferrisul per mo. (when used)	17,450	Mixed liquor	653
Air used (cu. ft. per gal. sewage)	0.08	Final effluent	50
Per cent of returned sludge	8.8	5-Day B.O.D. (p.p.m.):	
Excess sludge wasted to primary tanks:		Raw	174
M.g. per month	2.86	Primary influent	202
Primary sludge removed for filtering (gal. per mo.)	550,308	Primary effluent	148
Chemicals for conditioning of sludge:		Final effluent	57
$FeCl_3$ (lb. per mo.)	8,130	Total iron (p.p.m.):	
Wet Prestolime (lb. per mo.)	115,650	Raw	19
Vacuum filters:		Final effluent	8
Days run monthly	11.25	Expenditures (dollars)*	118,051.13
		Per m.g. for operating expenditures	25.93

*Includes $2,875.00 interest on bonds and $10,000 payment on bonds.

accident frequency and severity rates have been so greatly reduced as to indicate the importance of the corrective measures, no matter how seemingly minor.

Two of the original 500-c.f.m. blowers were replaced after 15 years of continuous operation. One of the replacement blowers is a rebuilt 1,000-c.f.m. unit; the other is a new 500-c.f.m. unit.

A summary of operating data for the year is given in Table II.

CYANIDE WASTE DISPOSAL SURVEY *

By Paul R. Carlson

Chemist, Sanitary District of Rockford, Ill.

On a number of occasions during the past 20 years of operation of the Sanitary District of Rockford (Ill.), fish kills have occurred in Rock River and its tributaries within the District boundaries. The causative agent in most every instance has contained cyanide salts of varying concentrations. The continuous presence of these cyanides in the streams has also had a detrimental effect on the lower forms of animal and vegetable life upon which fish feed.

A fish kill involving hundreds of rough fish and some game fish was reported to the District on July 17, 1951. The offending poison seemed to follow the west bank of the Rock River and was noticed as far south as Oregon, Ill. The origin of the substance causing this fish kill was traced to a concern which had discontinued a cadmium plating process and, in order to ready its equipment for a zinc plating operation, had dumped directly to the creek and thence into Rock River 6,500 gal. of plating bath containing 2.6 oz. of cadmium metal and 5.7 oz. of sodium cyanide per gallon.

As a result of this incident a meeting was held at the offices of the District on November 13, 1951, to discuss ways and means of controlling the release of cyanide-bearing industrial wastes to the sewers and waterways. Those present at this meeting included representatives from a majority of Rockford's and Loves Park's industries engaged in plating and heat treating of metals, engineers from the Illinois State Sanitary Water Board, and representatives from the Rockford Department of Public Health and the District. A sanitary engineer from the State Sanitary Water Board gave a talk on the toxic effects of cyanide-bearing wastes. The meeting concluded with a general discussion of the problems confronting industry and the District, with particular reference to cyanide wastes.

Cyanide Survey

An industrial waste survey was then suggested to determine the sources and concentrations of cyanides entering District sewers. Such a survey has now been completed. The results of this survey have been tabulated and give accurate information about the individual industrial concerns contributing to the total cyanide load now entering the sewage treatment plant.

During 1950 and 1951, many analyses of both the incoming sewage and the effluent from the sewage treatment plant have shown the cyanides, as CN, to average from 2 to 4 p.p.m. on a daily 24-hr. composite sample basis. These concentrations, when diluted with the normal flow of water in Rock River, which affords a dilution of 40 to 60 parts to one of sewage, do not kill fish, for if they did, fish kills would be ex-

* A condensation of a report to the Board of Trustees, The Sanitary District of Rockford, in July, 1952.

perienced almost daily. Deleterious effects on the treatment plant operation seem to be negligible as far as primary treatment is concerned, but would undoubtedly affect a secondary treatment process.

It becomes logical to conclude that fish kills in Rock River due to cyanide poisoning are brought about by the dumping of concentrated plating baths or large amounts of heat-treating residues. It is felt that the survey has caused the various industries concerned to become fully aware of their responsibilities and has brought about a better understanding of the release of cyanides to the sewers.

Treatment Study

During the period from January, 1950, to July, 1951, the author spent considerable time appraising the various methods available and used for the destruction and treatment of cyanides as found in metal-plating and heat-treating wastes. While these methods are successful and produce effluents which are not toxic to fish life or sewage treatment processes, they present a problem because of the high cost of the equipment and chemicals used.

The responsibility of continued operation whereby no fish kills or deleterious effects on the treatment plant processes due to cyanides are brought about should fall directly on the local industries. At present, it is not believed necessary to ask the industries to chemically treat their cyanide-bearing wastes if, by good housekeeping and careful operating procedures, they will keep dragout and spillage to a minimum and make no dumps of concentrated solutions without the knowledge of the Sanitary District.

At the meeting previously mentioned it was suggested that the Sanitary District erect a plant on its grounds for the chemical treatment of concentrated batches of cyanide-bearing wastes. The cost of such a plant, hauling and handling excluded, would be approximately $10,000, with the thought that industry would prorate both the expense of initial installation and the chemicals used in subsequent treatment.

After a study of the available literature it is concluded that treatment of these concentrated plating baths could and should take place in the original holding tanks in the respective industrial establishments.

Summary and Conclusions

1. The concentration of cyanides in the sewage entering the sewage treatment plant has averaged 2 to 4 p.p.m. as CN on a daily 24-hr. composite sample basis. Efforts to lower these concentrations should be continued.

2. The foregoing cyanide concentrations, when diluted 40 to 60 times with Rock River water, do not cause fish kills. However, they do have a deleterious effect on lower forms of animal or vegetable life in the waters of the rivers.

3. Concentrated batch dumps of plating solutions or heat-treating residues have undoubtedly caused the majority of fish kills experienced within the confines of the Sanitary District of Rockford.

4. The responsibility of preventing and controlling the further dumping of concentrated cyanide solutions should fall directly on the industries concerned.

5. At present, the cost of chemically treating the large volumes of cyanide contaminated rinse waters from plating and heat-treating operations is prohibitive.

6. Chemical treatment of concentrated batch solutions containing cyanides should be necessary before release to sewers. If possible, such treatment should be brought about in the original holding tanks in their respective locations.

7. The various industries and manufacturers contacted and concerned in the survey have given their wholehearted cooperation and exhibited a

willingness to do their utmost in overcoming this waste problem. With such a feeling existing, the control and treatment of cyanide-bearing wastes no doubt will be worked out to the satisfaction of all parties concerned.

THE DAILY LOG

Kenosha, Wisconsin

By Frank I. Vilen, *Superintendent*

August 15—We experience frequent breakdowns and considerable maintenance expense on the magnetos in the dual ignition systems on the pumping engines. These magnetos are of the same type as those used on heavy duty construction equipment and we are at a loss to understand why ours should not stand up as well as ones subjected to severe outside service. Local ignition men suggest a possible cause may be the lack of adequate ventilation and the presence of moisture, which, coupled with high voltages, set up ideal conditions for corrosion. A possible cure may be to change over to low voltage magnetos with step-up transformers at each plug, as are used in some airplane installations. This conversion would be quite expensive. Before deciding on a change, we will remove the felt filter pads from each side of the magnetos and install small fans to direct a current of air on them for added ventilation. If this helps, our troubles will be over.

August 23—A cable break in the power line to the sludge conveyor and grinding equipment caused a four-day delay in sludge removal operations. Most of this cable is easily accessible, but of course the break had to occur under the concrete walk next to the digester control room.

August 30—A colleague from a neighboring city paid a visit today. We talked mostly about working hours and plant personal schedules. During the conversation it was learned that the "in" temperature to his digester circulating water system is maintained as high as 200° F. with no caking.

September 18—Developed a howl in the No. 2 sewage pump—sounded like a bearing failure. This promised to be a tough job, as this pump had not been apart for 6 or 7 years. Sure enough, we broke the largest wheel puller available trying to remove the pump impeller from the shaft and ended up by hauling the whole assembly to the garage, where a large press was strained to the utmost to get the impeller off. Found that the thrust bearing had failed.

September 19—Spent the entire day visiting around with officials of various manufacturing plants in the city. This was time well spent, as we now have a better idea of their operations, the types of wastes, and likely sources of substances which may cause headaches at the treatment plant.

September 24—We are firm believers in the value of good public relations and avail ourselves of opportunities to tell the citizens about the treatment plant and the work we are trying to accomplish. One of our ways to reach the public is through the daily weather observations. Our weather data are broadcast from the local radio stations three time daily; any unusual conditions are good for a story in the newspaper; and we have been accepted as almost an official "out-of-the-horse's-mouth" in this field. When Joe Doakes calls up the plant and growls, "What-

cha mean, you only have 5 below down there? My thermometer says minus 15," we are happy about it. We know that Joe has found out there is a treatment plant, and some day he may become curious enough to pay us a visit.

September 26—Overhaul of the gas engine revealed considerable sludge in crankcase, a high water content, and the viscosity of the oil double what it should be. Consultation with an oil analyst resulted in a reduction in filter change hours, also in oil change hours, and installation of additional exhaust condensate traps to keep water out of the crankcase.

October 15—Some of our oil trouble may be due to the fact that one of the gas scrubbers has been out of service for I don't know how long. The scrubber has a three-way valve for by-passing it and someone had turned the valve to the wrong position.

October 17—Placed the primary digester out of service for cleaning. (The other one was emptied last year.) Past experience has established a routine for this job and no trouble is anticipated. It's just a nasty job and takes time.

November 3—The oil seals on all of the clarifier drives need replacement. Why can't items like these be standard so that we could get them locally? Nowadays it takes weeks to get anything from a source more than 50 miles away.

November 8—The crew piled up a large quantity of dirty old work clothes and set fire to them in the field back of the plant. Got a call from one of our neighbors, who complained that the smoke and soot was soiling her wash. The fire was put out in the interest of maintaining neighborly relations.

November 13—We are engaged in readying the plant for winter operation. All sill cocks have been drained, hoses put inside, pressure relief valves examined and filled with oil, and roof drains cleaned of debris and leaves.

November 16—No. 3 gas engine has been running hot. The trouble came from a leaky water pump and a partially clogged circulating system. All three sediment screens on the vacuum priming lines were cleaned. The overheating was seemingly caused by a thermostat which had corroded and stuck.

November 22—The digester is back in service. We are reminded of the story of Hercules and the Augean stables, and wonder where the State Board of Health boys were during his river pollution act.

The patent sludge pump packing installed 18 months ago is still in service and shows no appreciable deterioration. This is exceptional, as conventional packings have only lasted 2 or 3 months.

November 27—Three inches of snow yesterday, and this makes the third day of below zero temperatures. Winter is getting off to an early start.

December 2—Rainfall totaled 0.39 in. this morning, accompanied by thunder and lightning. It is rather late in the year for this kind of weather. Later, a routine check was made of all plug valves, and all electric motors were checked and greased.

December 13—One of our operators, in the Army Reserve, was called for active duty. He will be in for about 18 months, and we will have to find a replacement for that time.

December 27—Trouble with one of the gas engines. A cylinder head was found to be warped, so it was hauled off to a local shop to have it machined.

January 5—Here we go again! Gas production has been steadily decreasing for the past two weeks. Winter temperatures plus colder raw sludge equals less gas—just when our demand increases. This is the inevitable winter formula around here, and one almost wishes that we could take the plant south for the cold months. Tom Hay (Racine) says that, within reasonable limits, it isn't the lower temperatures as much as a sudden and extreme drop

in temperatures that starts the trouble. Maybe so. Up to now, however, it does not seem that an investment in compression and storage equipment is warranted.

January 9—The oil seal on the organic return gave up the ghost this morning. However. we found an identical one from a 1939 Dodge automobile and had the thing back in service in short order.

February 10—We are using great quantities of natural gas purchased from the utility to supplement the present sludge gas shortage. The meter pointer is spinning like mad, and we will have a sizable bill this year.

February 20—Both digesters are practically dormant. Digester volumes are being kept to a minimum, the circulating water temperatures have been increased, and the digester contents are being recirculated in the hope that this will start some activity again.

March 7—One of the sludge pumps plugged. Removal of a suction line elbow disclosed an aluminum funnel, which had somehow been wedged into it. The pump was restored to service but the funnel was a total loss.

March 17—The rollers on the spiral-guide gas holder are lubricated through a vertical grease pipe. Found some of the rollers frozen tight, and could not turn them with a 4-ft. chain wrench. When the rollers were removed, the grease lines were found to be plugged with dirt and rust. It was obvious that the grease grooves in the rollers were inadequate, so additional grooves were machined. A periodic inspection of the rollers was scheduled and it is hoped that this will not happen again.

April 11—We have not been able to find measurable quantities of materials which might be toxic and inhibit digestion, excepting, of course, our usual 0.4 per cent copper (as dry solids). The decrease in digester activity and consequent lower gas production always occurs in the winter months.

April 25—Contracted with the plant crew to paint the 2,100 sq. ft. of pump room ceiling. This job has never been done in the past without showing lap marks. We hang a scaffold from the travelling crane and use three men across the 32-ft. width. The agreement was that the men could go home when the job was finished. Result: a beautiful paint job and the men home by 2 p.m.!

May 15—We apparently have a couple of inches of oil in the digesters. Analysis indicated it to be a No. 3 fuel oil. We should barrel it and sell it back to the persons who sent it down here.

May 16—The plant chemist suggested that sludge volatiles seem unusually high at the same period each month. We plotted 4 months for 1950 and found peaks in the curve around the 18th to the 25th of each month. This suggests a periodic dumping and will serve as a clue for a local industry as to "wha' hoppened."

May 25—Oil seals on both flocculator drives failed within a couple of days of each other. Replacement was a simple task, except that the equipment is heavy and there is insufficient room to work and move things about.

May 31—Since last September, your reporter has spent considerable time visiting local industries. Now we are acquainted with most of the men in charge of operations and have some idea of their problems and waste disposal practices. Also, they have a better understanding of our problems. A cordial reception was accorded in every instance, and all promised their full cooperation should any industrial waste problem "rear its ugly head."

June 5—A 30-in. concrete pipe sanitary sewer serving a sparsely populated area in the northwest section of the city meanders through the municipal golf course, closely follows a branch of Pike Creek, crosses the creek at several points, and finally discharges into Pike Creek trunk sewer. Some rough flow checks on this sewer showed rates far in excess of its supposed present sanitary load. Many of the joints

are open and large quantities of creek water and infiltration find their way into this sanitary sewer.

June 14—Completed installation of a universal-type burner in one of the boilers so that either sewage or natural gas can be used.

July 10—An incident occurred today which is embarrassing to report since it was one of those things which should not happen if everyone exercised proper precautions. It is reported, however, as an example of one of the dangers encountered in plant operation and in the hope that our experience may serve as a lesson and a warning to others.

A pump in a drain sump used to drain comminutor channels failed this morning. Condensation from the exhaust gas heat exchanger drains into this sump as well as other drain waters. The sump can be entered only through an elliptical manhole just large enough to admit a man's shoulders if he holds his breath. It has been the custom to shut off both gas engine-operated sewage pumps (operating only on the electric pump) and to purge the sump thoroughly before entering it to make repairs. On this occasion these precautions were not carried out. As a result, one of the men became ill while in the sump. The condition was also aggravated by the fact that it was a hot, close, and humid day with no natural movement of air. The workman was able to get out of the sump unassisted, but required the services of a physician and administration of oxygen by the fire department rescue squad. The doctor called it monoxide poisoning. Fortunately, all that happened was a temporary indisposition for the man, but it could easily have been worse. This is one of those times when we can consider ourselves lucky and should pause to carefully review our safety practices and take steps to prevent mishaps of this kind.

TIPS AND QUIPS

Battery-Operated Emergency Handlamp

A new, durable, 7½-v., battery-powered handlamp is available for use as a trouble, work, or emergency light, either indoors or outdoors. The unit consists of a non-corrosive aluminum bracket with a rubber grip handle and two-way fingertip switch that mounts on a 7½-v. ignition dry-cell battery. The wire-guarded, 6-in., adjustable, chrome-plated head and reflector gives 3 c.p. on low beam and 21 c.p. on high beam. The sealed beam feature is available.

Details may be secured from General Scientific Equipment Co., 2700 Huntingdon St., Philadelphia 32, Pa.

Liquid Sludge Disposal

An indication of the advantages of liquid sludge disposal directly to crop lands under Canadian conditions is given in the following, abstracted from the 1951 Annual Report of H.S. Nicklin, city engineer, Guelph, Ont.:

Disposal of liquid sludge to farmers' fields by city-owned tank truck, commenced about 10 years ago, was continued. This system is more economical than the former contract system. In 1947, a Four Wheel Drive truck of 5-cu. yd. capacity was put in service; it serves double duty as a snow plow when needed.

A total of 7,070 cu. yd. of liquid sludge was distributed on 18 different farms during the year. The cost of sludge haulage was $0.49 per cubic yard for an average haul of 4 mi.

Several times during the year Superintendent H. Theaker interviews the individual farmers to discuss the best method and time of application. As a

result, not a single complaint was received during the year as to this method of sludge disposal. Also, objectionable odor due to the old method of drying sludge on open beds at the plant was entirely eliminated.

New Submersible Sump Pump

A new, revolutionary type of submersible sump pump or cellar drainer has been announced. The unusual unit has no protruding floats or rods, allowing the complete unit to be installed in the sump pit with no extended pump shaft above the floor level.

According to the manufacturer, Fairbanks, Morse & Co., the new unit has motor and operating switch completely enclosed in a stainless steel housing that keeps electrical parts clean and dry, even if submerged, and also functions as a float to control the pump operation. The only installation assembly necessary is discharge piping. The operating range is set at the factory and no float adjustment is necessary.

Disaster Scoreboard

Sludge Drier Explosion

On August 16, 1952, an overheated sludge drier exploded at the Milwaukee, Wis., sewage treatment plant. No injuries resulted and damage was limited to blistered paint on two driers. The overheating was attributed to lack of wet material resulting from failure of two conveyor belts. A chain of smaller blasts followed the initial explosion, but fires were extinguished with steam sprays.

Manhole Asphyxiation

On August 27, 1952, four men were killed by gas in a sewer manhole in Irondequoit, a Rochester, N. Y., suburb. Two employees of the town's sanitation department were overcome in the 14-ft. deep hole and two town firemen wearing masks (not of the oxygen-supply type) lost their lives when they went in to rescue them.

Manhole Oxygen Depletion

Two men of a sewer cleaning crew at Lansing, Mich., lost consciousness almost immediately upon descending into a manhole adjacent to a clogged line. Rescue squads were dispatched to the scene and a fireman went into the manhole with an all-purpose mask and a safety harness. He, too, became unconscious, but was brought to the surface immediately by means of the safety harness.

Equipped with oxygen-supply respirators, fire department personnel then succeeded in lifting the other two men out of the manhole. Although all three victims were given oxygen immediately and removed to the hospital, one man died.

Analyses of gases in the manhole after the accident indicated oxygen depletion to be the cause of the asphyxiations.

No Moans or Groans

According to the August, 1952, issue of *Safety News Letter*, published by the Public Employee Section, National Safety Council, the Sewage Treatment Division, San Diego, Calif., worked 63 men for the 12 months ending April, 1952, with no lost-time injury.

That's an enviable safety record!

Reviews and Abstracts*

Synthetic Detergents and Sewage Processing. *Jour. and Proc., Inst. Sew. Purif.*, Part 3, p. 351 (1949).

I. Introduction. By M. Elton.

The main developments in the synthetic detergent field are traced and the various types are described. A list of suggested deleterious effects of synthetic detergents in sewage treatment includes reduced primary sludge with consequent overloading of secondary units, reduced gas production, more difficult sludge dewatering, higher secondary effluent B.O.D.'s, and lower grease recoveries.

The concentration of synthetic detergents in sewage in various countries varies considerably because of synthetic detergent usage and water consumption.

II. Sedimentation of Sewage. By A. Sciver.

Laboratory studies were made on the effect of synthetic detergents on sedimentation. Sodium secondary alkyl sulfates were used throughout. The synthetic detergents produce an opalescence in sewage which was measured by photoelectric cells and standardized by using known amounts of fullers' earth.

It was reported that 20 p.p.m. of sodium secondary alkyl sulfates produced no effect on sedimentation or on oxygen consumed from $KMnO_4$. Increasing the concentration of detergents to 40 and 100 p.p.m. of active ingredients did adversely affect sedimentation, but no noticeable change was made in oxygen consumed from permanganate. Concentrations from 40 to 100 p.p.m. are probably 4 to 10 times stronger that would be expected to occur in the next 5 yr.

No practical measurement of suspended solids remaining after various periods of settling was made except by the Gooch crucible method, which the author suggested was quite unsatisfactory.

(It appears that the proper approach to this problem would have been to measure the amount of solids removed in the form of sludge. Had there been a correlation made between opacity remaining in the supernatant and the sludge removed, the study would have been more useful. This information may be forthcoming.)

III. Production of Methane from Sewage Sludge. By I. P. N. Degens, Jr., H. van der Zee, J. D. Kommer, and A. H. Kamphuis.

Laboratory experiments were conducted on the effects of varying amounts of several selected types of synthetic detergents upon methane production from a mixture of raw and secondary sewage sludges. For concentrations of active ingredients of synthetic detergents of less than 500 p.p.m., no noticeable effect is found on the quantity of methane produced. In general, concentrations of 1,000 to 5,000 p.p.m. inhibited gas production. The quality of gas produced was the same in all cases.

Another series of experiments demonstrated that primary sludge adsorbed or carried over to the digester less than 20 per cent of the synthetic detergent, whereas a mixture of waste activated and primary sludges carried over something less than 25 per cent of the active components of the synthetic detergent. Detergent consumption would have to far exceed present expectations to produce digester concentrations exceeding 500 p.p.m., which is roughly the upper limit for successful gas production.

Methane production from digestion of primary sludge only, was less in the presence of synthetic detergents than in the presence of fatty acid soaps, mainly because less materials settled out in the primary sludge with synthetic detergents present.

In a study of digested sludge relative to

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

filterability with varying amounts of detergents present, it was found for concentrations of less than 500 p.p.m. of active ingredients in the fresh sludge that there was little effect on filterability, but that for greater concentrations the sludges did not dewater well.

IV. Processing of Sewage Containing Wool Scouring Liquors, Etc. By H. C. Evans and P. A. Winsor.

Laboratory studies indicate that wool scouring wastes produced by synthetic detergents rather than fatty acid soaps can be cracked or reclaimed at the factory by adding a solution of aluminum sulfate (10% alumino-ferric solution) previous to acidification with sulfuric acid.

Studies conducted on Bradford sewage containing wool scouring wastes amounting to 4.1 p.p.m. active synthetic detergents, indicate no harmful effects of the presence of detergents on the sewage treatment processes. If there was an effect, it was small relative to other variables. Again, it was pointed out that aluminum sulfate aided in the treatment although it was admitted to produce a greater volume of sludge.

V. Effect of Synthetic Detergents on Certain Water Fauna. By I. P. N. Degens, Jr., H. van der Zee, J. D. Kommer, and A. H. Kamphuis. *Ibid.*, Part I, p. 63 (1950).

Amounts of synthetic detergents varying from 0.4 to 100 p.p.m. were added to 250-ml. B.O.D. bottles containing 4 ml. of sewage and allowed to incubate for 5 days. It was found that sodium secondary alkyl sulfate and sodium primary alkyl sulfate produced higher B.O.D.'s than did sewage alone. The other detergents had little effect on B.O.D. Sodium secondary alkyl sulfate delayed the B.O.D. reaction considerably, causing the 1-day and sometimes the 2-day B.O.D. to be zero, but once action began it very quickly exceeded the B.O.D. of sewage without the synthetic detergent.

Other experiments indicated that all synthetic detergents decompose biologically, some at much faster rates than others. This is measured by the B.O.D. reactions and also indicate that sewage treatment processes could be expected to remove more of some than other types of detergents. Air appeared to increase the rate of decomposition.

Laboratory experiments were conducted to determine the concentration of various synthetic detergents necessary to kill various species of fish. It was found that if a fish was immediately subjected to 5 p.p.m. of active synthetic detergents, death came within a few hours, but if acclimatized slowly, they could withstand even greater concentrations. This leads to the summarization that little concern should be given this factor as concentrations of these magnitudes would never exist, except possibly at sewer outfalls where no treatment was provided.

The Treatment of Meat Wastes. By John B. Rowntree. 30 pp., mimeo. (Aug., 1950).

This is a report by the author to the Auckland (New Zealand) Metropolitan Drainage Board based on his personal investigations made during a visit to the United States during July and August, 1949. His personal observations of American practice have been supplemented by a study of the available literature.

Plants investigated during the visit were those at Mason City, Iowa; West Fargo, N. Dak.; Madison, Wis.; South St. Paul, Minn.; Austin, Minn.; Sioux Falls, S. Dak.; Chicago, Ill.; Muncie, Ind.; Marshalltown, Iowa; as well as a number of meat packing and slaughterhouses. Data on strength of meat wastes and unit losses in meat wastes, as well as considerable operating data concerning unit loadings and efficiencies of the treatment plants investigated, are provided.

Among the conclusions drawn as a result of the study of American practice are the following:

1. The best way of easing treatment plant loadings is by careful "housekeeping" in the packing plant itself.
2. Meat wastes should as a minimum receive pretreatment to remove paunch contents and grease.
3. The main reduction of oxygen demand in the wastes should be by high-rate filters.
4. Two, and even three, stages of biological treatment are necessary for full treatment with wastes receiving little dilution.
5. The activated sludge process would

probably give satisfactory results where the meat wastes are heavily diluted, or heavily pretreated with fair dilution.

6. Flocculation to assist sedimentation has proved practicable and useful.

7. Problems connected with nitrification and rising sludge in final tanks require watching. A. P. TROEMPER

The Sewage Treatment Plant of Flers. By M. LEVIEL. *L'Eau*, **37**, 195 (Dec., 1950).

The city of Flers, France, all but destroyed during World War II, and presently under reconstruction, is being provided with a modern sewage plant utilizing an Aero-Accelator unit for activated sludge treatment. Expected advantages are: 50 per cent lower initial investment, simpler installation (no primary or secondary clarifiers), aeration time reduced to one-third, reduced operating cost because of increased efficiency, flexibility in regard to flow and strength variations, starting of system within a week, better resistance to accidental introductions of industrial wastes. The units of the plant consist of: comminutor, raw sewage storage tank, one Aero-Accelerator unit (31 ft. diameter, 14 ft. 9 in. high, 11,300 cu. ft. capacity) providing 2.5-hr. aeration at peak flows, one 31,000 cu. ft. digester, sludge drying beds, and air blowers (5 hp. each) providing an air flow of 147 cu. ft. per min. Two automatic pumps (3 hp., 3,300 g.p.m. each) lift the stored raw sewage to the Aero-Accelator. M. ALBANESE

Sanitation System of St. Dié. By P. H. DE BOIS-LUAY. *L'Eau*, **38**, 8 (Jan., 1951).

The city of St. Dié, France, destroyed during World War II, and presently being rebuilt, formerly had two separate sewer networks, one on each bank of the river Meurthe which passes through the town. Both systems discharged combined raw sewage downstream from St. Dié, a disastrous procedure, considering the small average flow (46 c.f.s.) and the tendency of the Meurthe to flood extensively over the low-lying banks.

The new sanitary network will keep the old sewers on the right bank for storm-water discharge; double them with a network of sewer mains (6 in. to 16 in. diameter) crossing the Meurthe through a 16-in. siphon to join the left bank network; on the left bank the old combined system will be kept and discharged in storm-water tanks (by-pass at low river flow). A complete sewage treatment plant will be constructed, fed by a general collector for both banks (20 in. diameter). The final outfall, downstream, will be used at low flows only; during floods, treated sewage will be lifted by pumps over the level of the water and the outfall closed to prevent flooding of the plant. M. ALBANESE

Sanitation of the Toulon Area. By A. JOWENT. *L'Eau*, **38**, 93 (June, 1951).

A collective sewage disposal project for Toulon (France) and four neighboring towns had been initiated in 1941, but rapid completion was necessitated by the World War II destruction of the Toulon sewer system and treatment plant, which was 30 per cent overloaded as early as 1924. Besides, three nearby towns had no sewer systems.

The new system comprises a storm sewer network discharging into Toulon Bay, and a sanitary trunk sewer serving Toulon and four outlying communities. Disposal at sea without treatment, at the end of Cape Sicié, 5 mi. from Toulon, is deemed satisfactory, because of great bottom depth and constant beating by waves.

The sanitary sewer is in two sections: one, serving Toulon and La Valette, is 11,260 ft. long, slope 0.00097, of reinforced concrete, oval section of 3 ft. 4 in. by 4 ft. 10 in., carrying 35.3 c.f.s. at three-fourths capacity at a flow speed of 3.94 ft. per sec. The second, extending the first, serves the three other towns and has a length of 21,200 ft., slope 0.0007, of reinforced concrete, oval (3 ft. 4 in. by 3 ft. 9 in.) with a 14-in. wide catwalk. This section was dug from the bottom of four shafts (135 ft. to 338 ft. deep) and at both tunnel ends. Many faults in the substratum, as much as 20 ft. wide, needed bridging with reinforced concrete. A manhole joins the two sections, and will eventually receive the sewage of two other outlying towns. The whole system will then serve 220,000 inhabitants, assuming a daily water consumption of 53 g.p.c.d., and is designed for 100 per cent overload over the hourly average flow.

The outfall at sea is protected against sand, waves, and rocks by a concrete pier of 100 tons poured into a concrete barge

previously sunk in proper position, in which the sewer ends in a T-shaped outlet. This project was financed by the Ministries of the Interior and of Reconstruction (75 per cent) and by the Intercommunal district of the Toulon area (25 per cent).

M. ALBANESE

Waste Treatment at the Montierchaume Distillery. BY M. RENARD. *La Tech. Munic. et Sanit.*, **45**, 226 (Oct., 1951).

This distillery, 5.2 mi. from Châteauroux-Déols (40,000 pop.), designed for 300 tons of sugar beet per day, discharged its untreated effluent in a tributary of the Indre River near this city's supply of spring water. These catchments were severely polluted by organic matter from distillery slops seeping through the fissured limestone during the very dry summer of 1949. Treatment by spraying over deeply plowed (1.5 ft.) ground was selected, the seepage ultimately to end in a small stream; filtration rate, porosity, and permeability coefficients were determined, along with the depth of ground over bedrock (3.3 to 3.6 ft. average) at a site approved by the state geologist, and adjudged sufficient for absorbing 3,780 g.p.d. per acre of mixed wastes (3/5 slops) and the maximum rainfall (2.62 in. per mo.) with a safety factor of 4 to 6. Spraying was effected with three removable rotary gun-type sprinklers connected with the plant's waste settling basins. Actual operation (Oct. 19 to Dec. 12, 1950) showed effective waste disposal by complete absorption by the ground (maximum time needed, 6 hr.), and no appreciable modification of the pH, clearness, odor, or fishlife of the small stream. An abnormal rainfall (6.5 in. in November) produced surface runoffs of dilute waste, but controlled release prevented bad effects, except a little growth of *Sphaerotilus* and green algae. Twice as much land, plowed along contours, is preferable to the present area. Continuous operation would insure more regular sprinkler functioning. Pipe and equipment corrosion will be avoided by mixing lime with the waste before spraying, instead of liming the soil directly. Fertilization by N, P_2O_5, K_2O from the waste is 10 to 50 times larger than normally needed for sugar beet or grain culture.

M. ALBANESE

Measurement of the Toxicity of Substances to Fish. BY D. W. M. HERBERT. *Surveyor*, **111**, 47 (Jan. 19, 1952).

Past experiments on the toxicity to fish of wastes and pure compounds are criticized, because conditions are not carefully stated, and often variables affecting the response of the fish are not taken into account. Consequently, the results of different studies cannot be well compared.

An apparatus is described in which long-term effects of known or suspected poisons may be examined, with all pertinent variables controlled.

M. C. RAND

Preliminary Processes in Sewage Purification. BY L. J. CAMPBELL. *Surveyor*, **111**, 55 (Jan. 26, 1952).

Certain problems and considerations in screening of sewage and grit removal are briefly discussed.

It is recommended that fine screens always be enclosed in a screen house, to insure their receiving the proper attention in bad weather. Screenings may be disposed of by disintegration or comminution, although either process reduces them in part below the settleable size, and increases the load on the secondary treatment unit or receiving water. Coarse screenings may be air-dried and burned. Various means are suggested for preventings and blockage of screens during storms.

The relative advantages and disadvantages of grit removal by constant velocity channels and Dorr tanks are considered.

M. C. RAND

Sewage Works Design. *Surveyor*, **111**, 75 (Feb. 2, 1952).

This article consists of the discussions of another by the same name, by John Hurley, which appeared in *The Surveyor* for November 17, 1951.

A question was raised about the author's recommendation that improvement of effluent quality might best be obtained by improving the final removal of solids. It was mentioned that addition of another unit for this purpose would have the disadvantage of increasing the complexity of operating the plant. The author replied, however, that often such measures might prove to be the most economical means of effluent improvement available.

There was considerable emphasis placed

by various discussors upon the frequent inadequacy of sludge drying area.

Two of the participants described ways in which sludge liquor, waste activated sludge, etc., are pretreated in existing plants before being returned to the raw sewage flow.

It was pointed out that most existing plants represent a compromise between efficiency of treatment and ease of maintenance. In smaller plants, ruggedness and reliability of the equipment become prime considerations. M. C. RAND

General Laboratory Layout of Medium-Sized Sewage Works. By RICHARD WOOD. *Surveyor*, **111**, 76 (Feb. 2, 1952).

On a large sewage works the provision of laboratory accommodation is taken for granted. On medium-sized works it is usual for at least a general laboratory to be provided, while on even quite small works, in cases where the sewage contains industrial wastes or the treatment plant is at all complex, a laboratory can be of very great assistance in the control of plant operation, in improving plant performance, and in providing data for use as a basis for future extensions. It is these general laboratories, found on all but the larger works, which are considered here.

Part I of the paper contains suggestions for the layout of such laboratories. Part II consists of a description of the laboratory at the Epsom works of the Epsom and Ewell Corporation, showing how some of the suggestions have been applied in practice. M. C. RAND

Chlorination of Digested Municipal Sewage Sludge. By F. V. AMMON AND F. WIESELSBERGER. *Gesundh. Ing.*, **73**, No. 1 and 2, 15 (1952).

Disinfection by chlorination of digested domestic sewage sludge is technically and economically feasible. Only thoroughly digested sludge should be chlorinated; active gasifying sludge requires materially higher chlorine dosages. If a 2-hr. contact time is considered sufficient for bacterial kill, NaOCl should be used; otherwise, $CaCl_2$. The max. chlorine requirement of digested sludge after 0.5-hr. contact time is 4 kg., after 1 hr. 5 kg., 2 hr. 6 kg., 3 hr. 16 kg., and after 4 hr. 21 kg. active chlorine per cubic meter of sludge. The active chlorine content of the disinfectant must be known, not the quantities needed for later disinfection. It is necessary to thoroughly mix the disinfectant with the sludge. W. RUDOLFS

Alkali Lignin to Stabilize Slow-Break Asphalt Emulsions. By W. A. MCINTOSH. *Ind. Eng. Chem.* **44**, 1656 (1952).

Pine wood alkali lignin is isolated from the waste liquors resulting from pulping pine wood by the kraft or sulfate process. The material can be obtained commercially in a dry form or in a concentrated solution. The alkali lignin acts as a sequestering agent and thus aids the emulsifying soap. Lignin is preferred over inorganic sequestering agents because it adds less ash to the asphalt.

Its availability will help the asphalt industry and may help to solve the problem of waste lignin disposal in the paper industry. R. S. INGOLS

Fats—A Source of Chemicals. By H. J. HARWOOD. *Chem. Eng. News*, **30**, 1282 (1952).

Many reports on the rapidly increasing production of synthetic detergents have been made recently. The market price of edible oils to the consumer has recently taken a sharp drop. These factors have combined to make fat purification residues very difficult to sell. Thus, this article on "fats" as a source of raw chemicals is particularly timely and points up the wish to return fatty acids and fats to the wastes from edible oil and meat production plants. It can be hoped that a profitable outlet for fats other than soaps can be developed as the use of synthetic detergents replaces the use of fats for soap.

R. S. INGOLS

Waste Products Now Plant Fuel. ANON. *Chem. Eng. News*, **30**, 2402 (1952).

Enamelstrip Corp. has described the first industrial installation of an oxidizing catalyst created by E. J. Hondry. The enamel company was venting xylene to the air, but is now able to obtain 90 per cent of its fuel requirements for its ovens from the catalyst heaters. The catalysts consist of porcelain rods coated with alumina and platinum alloy.

R. S. INGOLS

Cane Sugar Bagasse Offers New Source for Newsprint. ANON. *Chem. Eng. News*, **30**, 2708 (1952).

A plant producing newsprint and paper board from cane sugar bagasse is now in operation at Paramonga, Peru. It is of interest to the waste treatment field that only 1.1 tons of bagasse are required to produce 1 ton of a high class paper. The waste of 0.1 ton would be low for the production of waste from wood.

R. S. INGOLS

Mine-Acid Stream Pollution Can Be Controlled. ANON. *Chem. Eng. News*, **30**, 3006 (1952).

S. A. Braley, of the Mellon Institute, described a method of controlling stream pollution from mine acid of strip mining. Acid formation is to be prevented by the use of impervious water layers over the sulfur, thus reducing the oxidation of the sulfur. The reduction in water flow will also reduce the flow of acid formed to the stream. Proper sloping of the surface will aid in keeping water from the sulfur-bearing strata. R. S. INGOLS

Sewage Treatment. BY JOZEF STIKSA. *Gaz, Woda i Tech. Sanit.* (Polish), **26**, 1, 9 (1952).

Before reviewing sewage treatment practice under Polish climatological conditions the author presents a resumé of regulations pertaining to the discharge of wastes into public watercourses. German regulations cited indicate that a dilution of 1 part waste to 50 parts dilution water is the dividing point between the need for primary and secondary treatment. In the United States the self-purification capacity of the stream should not be exceeded or 200 l. per second of flow should be provided for the sewage discharged from 1,000 inhabitants. In Czechoslavakia the stream below the point of discharge should be of the same sanitary quality as that above. English standards call for a waste effluent containing no more than 30 p.p.m. of suspended solids and 20 p.p.m. of 5-day B.O.D. Where a dilution factor of from 1:50 to 1:300 is available, 75 p.p.m. B.O.D. may be discharged; for a dilution in excess of 1:500 wastes may be discharged following screening and grit removal.

An extended discussion is presented of Belgian standards, which list volumetric loading factors for septic tanks (3-unit tanks), Imhoff tanks, and biological filters, along with general regulations pertaining to odors, sludge removal, sample collection, effect on microflora and microfauna, methylene blue stability, etc. Also where dilution factors amount to less than 1:5, the suspended solids and 5-day B.O.D. values should not exceed 30 p.p.m.

The basic sewage treatment units or processes discussed are screens and racks, grit chambers, primary sedimentation, digestion tanks, biological secondary treatment, secondary sedimentation, chlorination, sludge drying beds, gas collection equipment, and pumping equipment. According to the author, biological treatment of wastes has passed through three phases during the last 50 years. During the first 25 years, open trickling filters were built; during the next 13 years activated sludge plants were most popular; and at the present time closed, artificially ventilated trickling filters are employed most frequently.

For operation under Polish conditions the following comments are offered. Backs and screens shall be either hand or manually leaned dependent upon the amount of waste treated. In general, horizontal-flow type grit chambers are used, except where rapid changes in flow occur when vertical flow units are provided. Primary settling basins are of the up-flow type in small installations and horizontal-flow type in large installations; the latter requiring special sludge scraping mechanisms. Separate sludge digestion tanks are provided in about 99 per cent of the cases; these have the advantage of permitting gas recovery. Small prefabricated Imhoff units are used for handling wastes from individual homes. The simplest form of biological treatment, and that most frequently used at present, is that provided by covered, artificially ventilated trickling filters; open filters are used in the smaller installations. In some cases, activated sludge units have been used, but the Haworth system employed in Kielce freezes when the temperature drops below −16° C. At Zakopane an open filter has not frozen at −33° C., but this is due to the fact that an 11-min. dosing cycle is used. Secondary settling basins are similar to primary units. Chlorine compounds are

used in small installations for disinfection, but chlorine gas is preferred in the larger ones; detention time in the basins being 30 min. Open sludge drying beds are used most frequently in Poland and every effort should be made to use the sludge for agricultural purposes. Centrifugal pumps are used most generally to pump the sewage where this is necessary.

CONRAD P. STRAUB

Stream Protection. BY ADOLF JOSZT. *Gaz, Woda i Tech. Sanit.*, (Polish), **26,** 1, 21 (1952).

In addition to its natural flow, a stream also receives domestic sewage and industrial waste flows. The official purpose of stream protection is to control the discharge of waste materials into the stream so as not to exceed its self-purification capacity. Wastes come from two main sources: domestic sewage from the daily use of water by mankind and from industry. The former does not vary markedly from municipality to municipality; the latter varies considerably, depending on the size of the industry, the manufacturing process, the degree of pretreatment provided, etc. It is reported that domestic sewage flows will amount to from 60 to 250 l. per day per person, varying with the environmental and cultural habits of the people, and will contain approximately 35 g. of grease per person per day (which is in accord with Russian and German data). In addition, the solids removed from sewage, when digested, will produce about 14 l. of methane gas per person per day. Care must be taken in the discharge of industrial waste to prevent the discharge of toxic elements.

The author describes the steps that have been taken in Upper Silesia in coping with the problem of stream protection. A committee comprising interested governmental and provincial groups has been activated to study the problem. One of their functions is to determine the nature and amount of waste being discharged from some 800 industries in the area. To date about 200 of these have been examined and studied. An expert committee makes recommendations for alleviation of the waste problem by recommending recovery, change in process within the industry, waste treatment, etc. CONRAD P. STRAUB

Principles for Calculating Flows in Separate and Combined Sewers. BY WACLAW BLASZCZYK. *Gaz, Woda i Tech. Sanit.* (Polish), **26,** 1, 24 (1952).

Following a review of the theory of calculating combined sewer flows by means of several expressions, the author presents time-intensity plots proposed by various authorities for Warsaw, in which intensities for a rainfall of ½ min. vary from 25 to 202 l. per sec. per hectar; for $t = 1$ min., i varies from 16 to 124; for $t = 2$ min., i varies from 12 to 70; and for $t = 3$ min., i varies from 9 to 58. In many projects, the results are based upon the experience of the designer, and vary from designer to designer as indicated by the data cited above. Accordingly, the author proposes that it is necessary to come to some agreement as to the coefficient of probability to be used for economical sewer design, and that it should not be necessary to depend wholly upon the judgment of the designer. Of course, the establishment of suitable norms must be based upon thorough and complete calculations and review of existing data. No one, according to the author, has dependable results, as practically none of the designers have had the opportunity of confirming their calculations in practice, because in many cases the system has not been completed as designed, the drainage area has not been fully settled, or the rains designed for have not occurred. CONRAD P. STRAUB

Sewage Disposal by Land Irrigation. BY JAN WIERZBICKI. *Gaz, Woda i Tech. Sanit.* (Polish), **26,** 2, 34 (1952).

A description is given of a land irrigation system in Lower Silesia, which was built in 1906 and has continued in operation until the present time. Data are presented on soil variation with depth in irrigated and non-irrigated soils, as well as the humus, P_2O_5, and K_2O contents, and the pH changes. There was an increase in the humus content, and an increase in the P_2O_5 content below a depth of 10 cm., an increase in K_2O content in the first 10 cm. of depth, and the pH has decreased from about 6.0 to about 5.7 during the irrigation period. The fields are located 3.5 km. from the town, which contributes approximately 550 cu. m. of waste daily. This waste is diluted by discharges from springs to a total volume of 1,100 cu. m. The

wastes flow by gravity to settling basins located at the irrigation field. Settled wastes are discharged to 73 parcels, each of which receives 6 to 8 applications per year totaling 300 to 400 mm. of sewage. All but four parcels are irrigated for 10 months and are mowed 3 to 4 times annually. The remaining four parcels are plowed and are irrigated throughout the year. On these 4 fields vegetables are grown and good yields have been obtained with tomatoes, white cabbage, cauliflower, cucumbers, and onions, but the yield with celery has not been encouraging. The parcels are not irrigated during the vegetable growing season. From the public health standpoint it is reported that no illnesses have occurred among the workers in the fields, some having been employed for over 30 years, and that there have been no outbreaks of disease attributable to the agricultural utilization of sewage wastes.

CONRAD P. STRAUB

Semi-Microextraction Method for Determination of Grease in Sewage. BY WŁADISŁAW HERMANOWICZ AND JANINA MATEJAK. *Gaz, Woda i Tech. Sanit.* (Polish), **26**, 3, 76 (1952).

A semi-microextraction technique developed by the authors for the determination of grease in sewage permits measurement of grease in samples containing from 0.2 to 30 mg. of grease in from 20 to 30 min. The amount of grease found in sewage is reported at 5 to 10 g. per person per day, or 50 to 100 mg. per liter of sewage. Industrial wastes contain larger amounts (as, for example, slaughterhouse wastes, 200 to 450 mg. per l.; tanneries 39 to 379 mg. per l.; cellulose factories, 4,100 mg. per l. as resin and grease; and textile factories, 500 to 12,000 mg. per l.) Russian sources define grease as all substances which are extracted with the aid of dry petroleum ether (B.P. 45° to 65° C.), whereas in "Standard Methods" (U.S.A.) grease is defined as that material which can be extracted from acidified material by petroleum ether (B.P. 40° to 60° C.). A modified apparatus consisting of an outer flat-bottomed tube, a condenser, a small siphon chamber, and a collecting dish is used in the analysis. Recovery of 99.5 to 100 per cent of added grease was obtained using chloroform, ethyl ether, or petroleum ether as solvents. To determine the grease content of sewage, 100 ml. of sewage are evaporated almost to dryness on a water bath, acidified to a pH of approximately 1 with HCl, and evaporated to dryness. The solids remaining are gathered on shreds of blotting paper, and placed in the extraction tube. Three ml. of the solvent are added to the dish in the bottom of the apparatus. Curves for extraction rates with chloroform, ethyl ether, and petroleum ether show that extraction was more rapid and complete with chloroform than with the other solvents used. In 25 min., 100 per cent of the grease was extracted with chloroform, whereas smaller portions were extracted with the other two solvents. The method calls for 30-min. extraction, after which the solvent is volatilized, the grease and dish dried for 10 min. at 103° C., and the grease weighed after cooling.

CONRAD P. STRAUB

Joint Materials for Vitrified Clay Pipes. BY HAROLD E. BABBITT. Civil Engineering Studies, Sanitary Engineering Series No. 3, Univ. of Illinois, Urbana, Ill. (1951).

The investigation included a laboratory study of the physical qualities of various materials used in joining vitrified clay pipes and the determination of the composition of joint compounds which should give satisfactory service. Joint materials tested were bituminous compounds, cement mixtures, and sulfur compounds.

The author concluded that watertight joints can be made with any of the proprietary, poured, bituminous compounds tested and with either Portland cement or with hydraulic cement. Cement joints can be improved, both in ease of making and in watertightness, by the addition of certain plastic materials. None of the cold bituminous materials and none of the poured sulfur compounds tested could be relied on to give watertight joints in all cases.

Poured bituminous materials which have the properties and constituents of the best material can probably be depended on to make watertight joints when carefully made under favorable conditions. Other poured bituminous compounds whose constituents and characteristics differed from those of the "best" material were used successfully to make watertight joints, but the results were not always certain.

Joints made with Portland cement in

the proportions of 0.25:1:1.5 of plastic material:cement:sand with a water-cement ratio of 0.6 to 0.7 gave the greatest number of watertight joints, provided the joint was kept moist while curing.

Watertight joints can be made with Portland cement or with hydraulic cement mortar, although more dry joints will be made with the former than with the latter material. Satisfactory mixtures of cement and sand in which plastic materials had not been mixed were found to be about 1:1.5 for Portland cement and hydraulic cement, with a water-cement ratio of 0.6 to 0.8.

Joints can be made more easily and less skill is required in making them with cement mortar than with poured materials. The principal objection to cement-mortar joints is their rigidity, which permits no movement of the pipe without breaking the joint. Although the joints are strong, when broken they will leak badly, whereas poured bituminous joints will allow some movement of the pipe before leakage will occur through the joint.

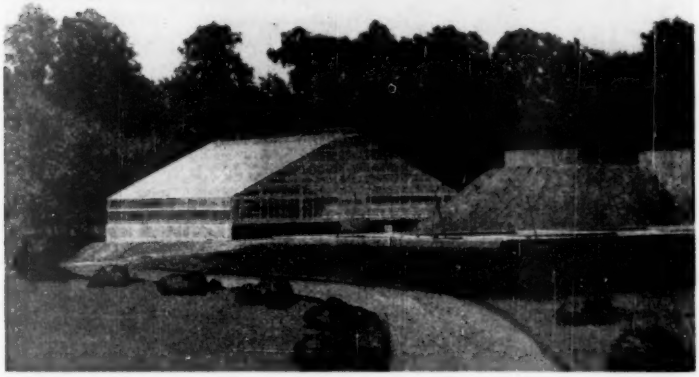
The tests on root penetration were inconclusive because no joint tested was penetrated by roots. H. P. ORLAND

Control and Removal of Radioactive Contamination in Laboratories. Nat. Bur. of Stand. Handbook 48. U. S. Govt. Printing Off., Washington, D. C. Price, $0.15 (1951).

This handbook gives detailed information on laboratory procedures designed to minimize the possibility of any accident involving radioactivity and to minimize the effects if such accidents do occur. In addition to including a number of general safety precautions, the handbook contains specific recommendations and discussions intended primarily for the guidance of such users of radioactive isotopes as universities, hospitals, etc. Permissible levels of contamination are discussed, as well as decontamination procedures for the skin, clothing, bedding, laboratory tools and glassware, floors, work benches, hoods, etc. Emergency procedures also are outlined.

H. P. ORLAND

at DOVER, DELAWARE



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Proceedings of Member Associations

NEW ENGLAND SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 1952 Spring Meeting of the New England Sewage and Industrial Wastes Association was held at the Hotel Elton, Waterbury, Conn., May 22 and 23, 1952. It was attended by 147 members and guests, which included 25 ladies.

At the sessions on May 22, the following technical papers were presented:

"Design Features of the Waterbury Sewage Treatment Plant," by Robert D. Mitchell, Malcolm Pirnie Engineers, New York, N. Y.

"Operational Features of the Waterbury Sewage Treatment Plant," by Walter M. Kunsch, Superintendent of Sewage Treatment, Waterbury, Conn.

"Alterations and Additions to the Sewage Treatment Plant at West Haven, Conn.," by Edwin B. Cobb, Project Engineer, Metcalf and Eddy, Boston, Mass.

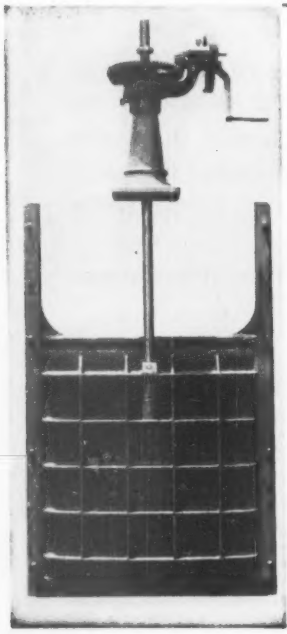
"Synthetic Detergents—Their Effect on Sewage Treatment," by Peter G. C. Isaac, King's College, England.

"Treatment of Metal Plating Wastes," by Walter Zabban, Yale University.

"Problems Experienced at Sewage Treatment Plants Because of Industrial Wastes," a symposium of five prepared discussions.

The afternoon program closed with a most enjoyable social hour for all members and guests.

(*Continued on page 500a*)



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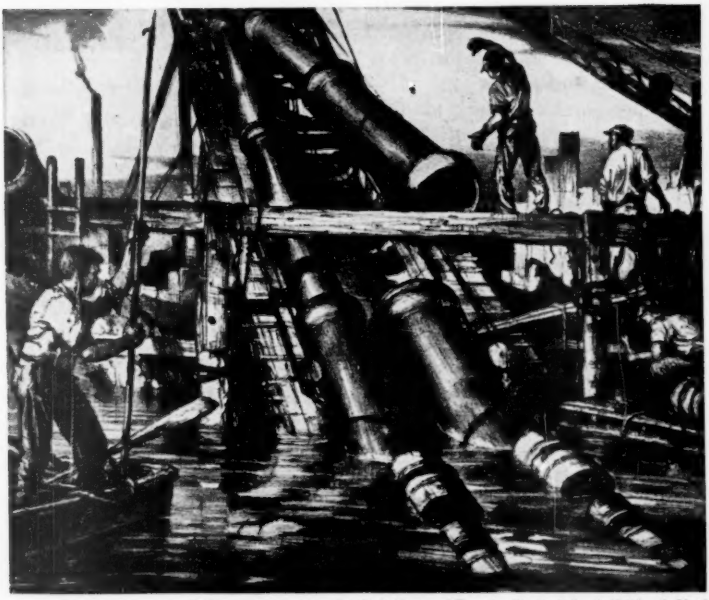

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The morning program for the second day comprised concurrent symposia, one on industrial wastes, the other for sewage plant operators.

The sewage plant operators' meeting had the general topic, "What's Right With My Plant?" Several prepared discussions were followed by general discussion.

At the industrial wastes meeting, three prepared papers were presented:

"Attitudes in Approaching Industrial Waste Problems," by W. E. Williams, Sanitary Engineer, Naugatuck Chemical Co., Naugatuck, Conn.

"Treatment of Industrial Wastes at the American Screw Company," by R. E. Ostby, Jr., Engineer.

"Treatment of Pulp and Paper Mill Wastes," by Joseph F. Baigas, Jr., National Council for Stream Improvement.

WALTER E. MERRILL,
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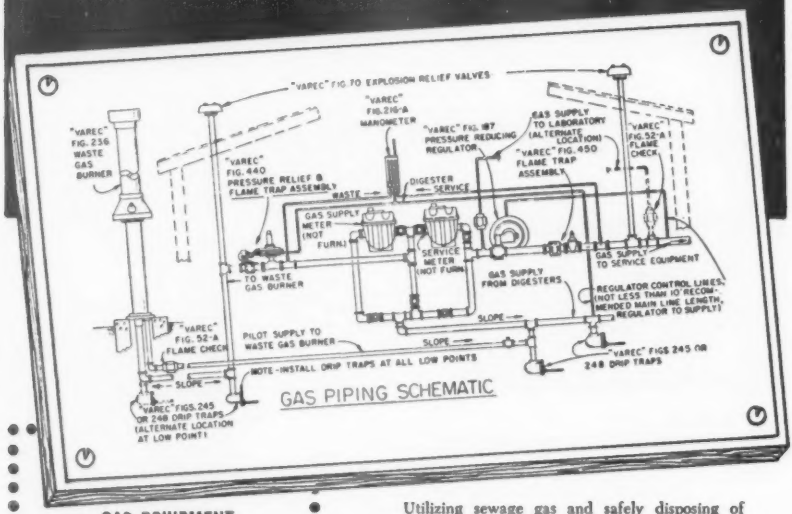
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 187 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 52-A FLAME CHECK
"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
WASTE
DIGESTER SERVICE
GAS SUPPLY METER (NOT FURN.)
SERVICE METER (NOT FURN.)
GAS SUPPLY TO SERVICE EQUIPMENT
TO WASTE GAS BURNER
GAS SUPPLY FROM DIGESTERS
REGULATOR CONTROL LINES (NOT LESS THAN 10' RECOMMENDED MAIN LINE LENGTH, REGULATOR TO SUPPLY)
SLOPE
"VAREC" FIG. 52-A FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
"VAREC" FIGS 245 OR 248 DRIP TRAPS
NOTE - INSTALL DRIP TRAPS AT ALL LOW POINTS
SLOPE
"VAREC" FIGS. 245 OR 248 DRIP TRAPS (ALTERNATE LOCATION AT LOW POINT)
GAS PIPING SCHEMATIC

GAS EQUIPMENT SPECIFICATIONS

a. **PRESSURE RELIEF AND FLAME TRAP ASSEMBLY**
"VAREC" Fig. No. 440

b. **FLAME TRAP ASSEMBLY**
"VAREC" Fig. No. 450

c. **FLAME CHECK**
"VAREC" Fig. No. 52A

d. **EXPLOSION RELIEF VALVES**
"VAREC" Fig. No. 70-1

e. **WASTE GAS BURNER**
"VAREC" Fig. No. 236

f. **DRIP TRAPS**
"VAREC" Fig. No. 245 (automatic)
"VAREC" Fig. No. 248 (hand operated)

g. **MANOMETERS**
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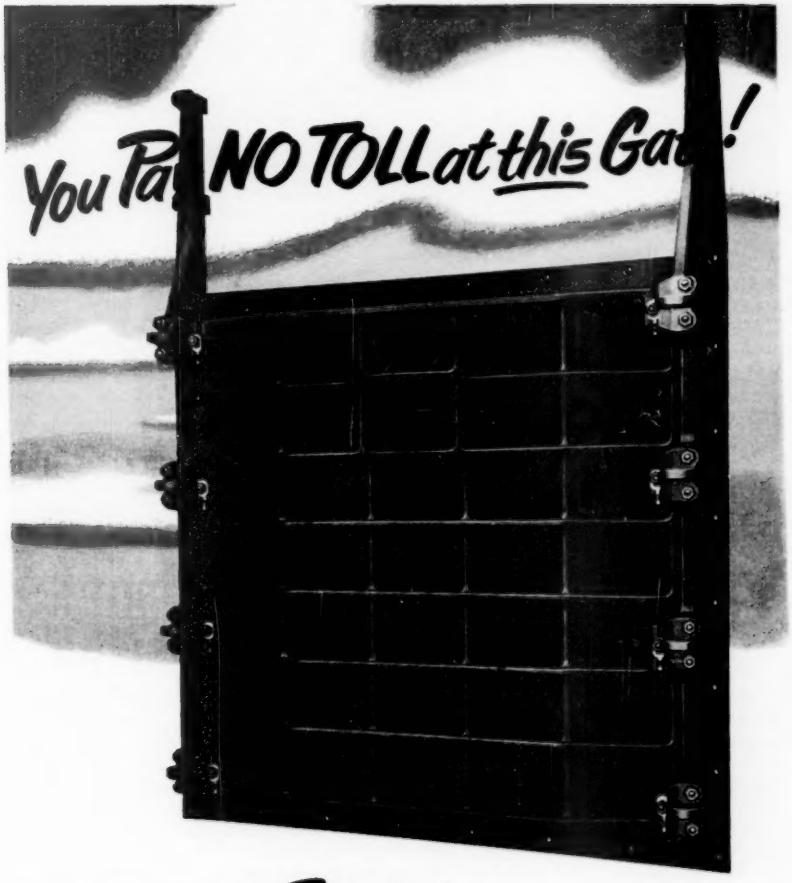

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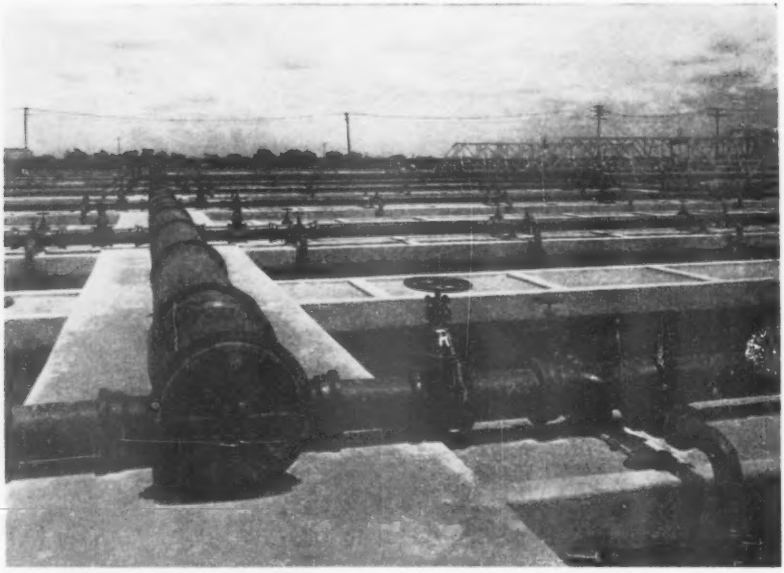

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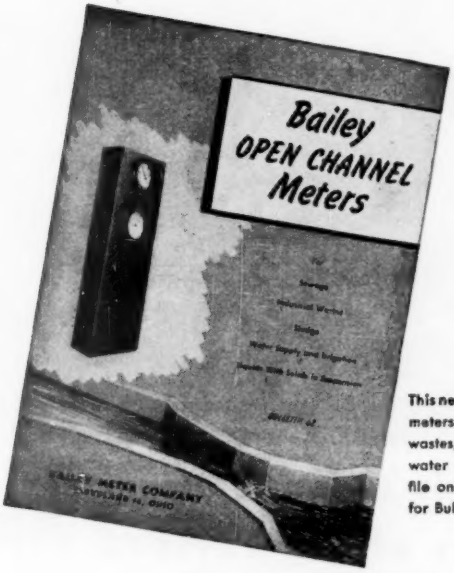

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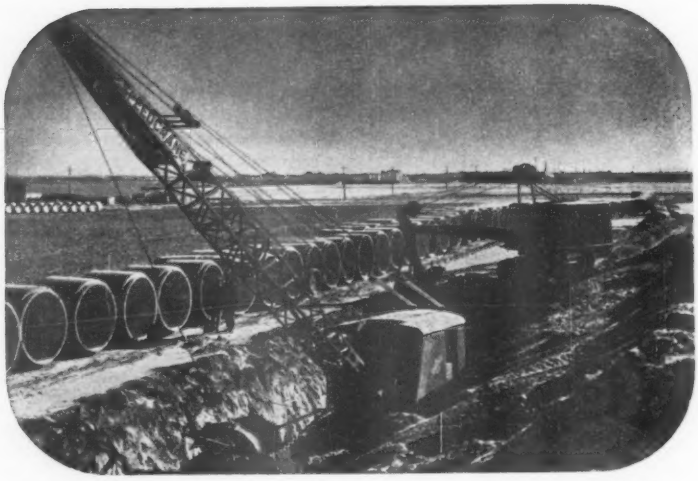

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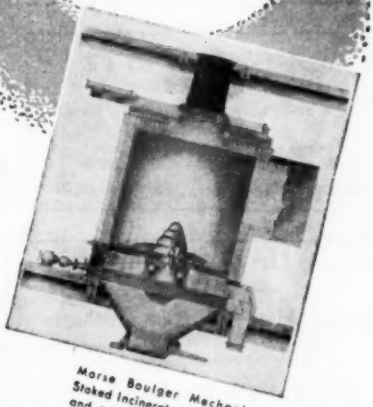

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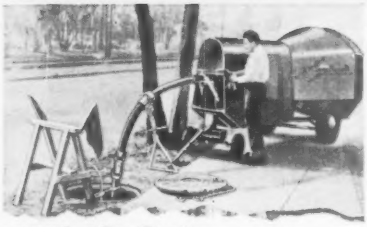

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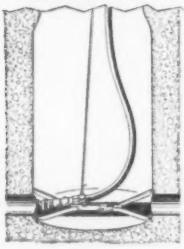

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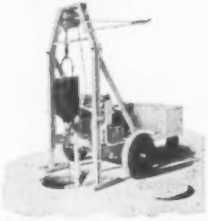

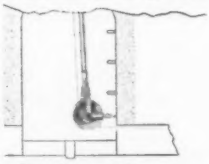

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